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DATA TRANSMISSION VIA SATELLITES FOR AIRCRAFT
MALFUNCTION DETECTION AND PREDICTION

A THESIS

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MALFUNCTION DETECTION AND PREDICTION

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TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS.	ii
LIST OF TABLES	iv
LIST OF ILLUSTRATIONS.	v
SUMMARY.	vii
Chapter	
I. INTRODUCTION.	1
Early Problems	
Early Applications	
Current Applications	
Types of Communication Satellites	
II. MALFUNCTION DETECTION AND PREDICTION FOR AIRCRAFT	8
Nature of the Problem	
Decision Theory Approach	
III. SYSTEM DESIGN	21
Use of Satellites	
Speed, Position and Tracking (SPOT) System	
Ground-Aircraft, Aircraft-Ground Communication	
Final System Design	
IV. CONCLUSIONS	46
APPENDIX	48
LITERATURE CITED	89
Other References	

LIST OF TABLES

Table	Page
1. Design Parameters for UHF-UHF and SHF-UHF Links	37

LIST OF ILLUSTRATIONS

Figure		Page
1.	Basic Design of an Active Satellite	6
2.	Basic Links	9
3.	Basic Detection Schematic	12
4.	"Good System" Probability Density	13
5.	"Bad System" Probability Density.	13
6.	Likelihood Ratio $\Lambda(r)$	14
7.	Bayes Decision Rule for Single Sample	14
8.	Two Signals and Two Samples	16
9.	Likelihood Ratio $\Lambda(\underline{R})$	17
10.	Bayes Decision Rule for Double Sample Case.	18
11.	Links Necessary for Determination of SPOT	26
12.	Satellite Orbit and Total Number of Satellites for Worldwide Coverage.	27
13.	Sample Link Block Diagram	29
14.	Typical SPOT Receiver	30
15.	Autocorrelation of PN Code.	33
16.	Crosscorrelation of PN Codes.	33
17.	UHF-SHF and UHF-UHF Links	34
18.	SNR _n Versus RF Bandwidth $\left[\rho = \frac{B N_w}{P_t} \right]$	36
19.	CPSK-PN Links with: (a) CDM; (b) FDM; (c) TDM.	38
20.	Basic CPSK Receiver [9]	39
21.	Basic CPSK-PN Transmitter	41

Figure	Page
22. Typical CPSK-PN Ground Receiver	42
23. CDM-PN Ground Transmitter	44
24. TDM-PN Ground Receiver.	44
25. Block Diagram of Final System Design.	45

SUMMARY

The objective of this research is to develop and design a system able to detect and/or predict in advance the malfunction of aircraft systems on long range missions. It is desired to receive at the ground control facility continuous data on performance of various systems on the aircraft (an engine, structure, etc.) and then, after analysis, give appropriate instruction back to the aircraft (replace system, land aircraft, etc.). The development of an adequate communication system is an important part of the research.

By 1975 huge and expensive aircraft will be operating in full capacity to fulfill world demands. Due to safety and economic reasons, a continuous worldwide surveillance may be necessary. The use of satellites for this communications application is analyzed in this study.

The detection of an aircraft system malfunction may be viewed differently for different applications; it may be of interest to detect if a system is "bad" or a system is "good." If a "bad" system has been detected on an aircraft, accurate prediction of whether the system will get "worse," stay as it is, or get "better" might be important, or "prediction" could involve a "good" system going "bad." In the event of detected or predicted malfunctions, precise speed, position and tracking of the aircraft may be necessary. With this information on hand, the ground station can process and study the information and give appropriate instructions to the pilot of the aircraft.

Although the design and development of a system able to detect and/or predict in advance the malfunction of aircraft systems is the primary objective of this research, the second objective is a system for determination of the speed, position, and tracking of the aircraft. These involve two-way communication between the aircraft and ground control via satellite and data processing in the ground control facilities. The modulation, multiplexing, and signal design aspects of the communication links are studied.

Following the study of these associated areas, a final system design based on the modulation, multiplexing, the necessary links, is specified. A considerable portion of the study involves the choice of the link and modulation for the final system design. The data used for the calculations are obtained from reference 11; the calculations obtained reflect typical satellite communication parameter values. Since it is ideal to obtain maximum efficiency with minimum weight and cost, an important parameter becomes the energy the satellite supplies; given the signal-to-noise ratio, the satellite receiver noise power density, and the data rate, the link that requires the least power transmission from the satellite is chosen. The transmitter and receiver needed on the aircraft, satellite, and ground control facility are given in block diagram form.

CHAPTER I

INTRODUCTION

Early Problems

A century ago people did not imagine man's eventual flying. Thirty-three years later people thought that the Wright brothers were wasting time and money building the first "flying machine." Twenty-four years later Lindbergh became the first man to cross the Atlantic on a solo non-stop flight from New York to Paris in the "Spirit of St. Louis." Then the jet age arrived and in the last two decades the rocket age got a firm start thanks to the continuing research of Robert Goddard. The requirement of the United States defense department to deploy a rocket powerful enough to deliver a nuclear warhead on a radius of at least 3000 miles from its launching pad led to and permitted the launching of satellites as communication relays.

Ten years ago the launching of a satellite was extremely difficult. The rockets available then had little thrust; weight became a severe limitation for launch. The structure of the rocket has to be designed to withstand conditions of vibration and shock during launching and to have a maximum degree of dynamic stability. Attitude stabilization, essential for control and weight reduction, was a problem. Reliability of the electronic equipment used to communicate was greatly decreased due to lack of temperature control. The solar cells did not provide a lasting power for the launching cost to be justified.

All possible atmospheric phenomena had to be studied to compensate for possible orbit abnormalities. A telemetry system for monitoring the performance of the communication systems was not reliable. Light, simple and high gain antennas had to be designed. Ground control facilities lacked a command system to obtain maximum efficiency from the satellite. The cost of launching a satellite was extremely high; an average of three launch attempts was necessary to achieve one successful launch.

An important parameter of space communication is effective energy (the energy necessary to transmit the required information over the distances characteristic of the missions [1]). Another important parameter of space communication is the energy per bit of information. This energy per bit of information is limited by the effective energy of the system; this in turn is limited by the satellite efficiency and the power generators. Solar cells were low power generating sources and very inefficient. The power supply, the power amplifiers, temperature control, the antennas, both in the air and on the ground, and the initial stages of the receivers are critical energy determining components.

The problem of providing sufficient energy may be divided between (1) the amount of energy available in the satellite and the aircraft, (2) the degree to which that energy can be directed toward the receivers, and (3) the efficiency of the receiving system in detecting this energy in the presence of noise. The effective power available from the aircraft and the satellite may be increased by increasing the

transmitter power, increasing the transmitter efficiency, or by increasing the antenna gain. The receiving system may be improved by increasing the receiving antenna area, therefore increasing the gain and the weight, and/or by decreasing the effective noise temperatures in the input circuits of the receivers.

Another problem encountered and of extreme importance concerns the most favorable orbits. A satellite orbiting about the earth at some distance less than 22300 miles and in a non-equatorial orbit, appears to oscillate about the equator in such a manner that the points on the earth's surface defined by a line drawn through the center of the earth to the satellite oscillate between extremes of latitude defined by the equator-crossing angle of the satellite's orbit and the equator [2]. A satellite on an equatorial orbit at an altitude of 22300 miles does not present this problem. The shape of the orbit is determined by the accuracy of launch; not only is it necessary that the velocity needed to travel in a circular orbit at a specified altitude above the earth be precisely correct at the moment of launch but it is also necessary that the angle be accurately controlled with respect to the earth's equatorial plane so that the proper orbit is entered and the velocity thrust be along a line tangent to the circular orbit desired. If the elevation angle of this thrust velocity is too high or too low, the satellite will either fall on the earth or enter an elliptical orbit. For maximum lifetime in orbit, space stations must be launched in orbits whose perigee (nearest distance to the earth) is at least 1000 miles; for a perigee of less than 1000 miles, the drag

of the atmosphere is sufficient to cause a measurable slowing of the satellite, the orbit turning into a spiral moving down to the earth's surface. The greater the orbiting altitude the greater the orbital period.

These early mentioned problems are some of the main problems encountered; to solve those problems many calculations and much experimenting had to be done. To increase the efficiency the transmitting power and the receiver sensitivity must be high; antenna gain must be high; transmission losses, tracking error losses and altitude control losses must be minimized. A good choice of the modulation technique, the link, and a favorable orbit will increase efficiency, resulting in reduced weight and cost.

Early Applications

Early applications of satellites were for equipment testing, radiation intensity measurements and re-entrance studies of future space vehicles. Other applications were radio and TV linkage of some European countries with the United States, studies on living cell reactions to weightlessness, and military purposes.

Equipment testing was the primary objective of the first launches made; as satisfactory results and the problems involved in getting those satisfactory results were solved, more and more satellite applications were found. Through experience and progress resulting from research, equipment reliability increased, reducing the cost of launching a satellite; with this the defense department found a lot of uses of satellites and further studies were made to improve the efficiency.

Different types of satellites were tested with the results obtained providing the basis for further improvements and applications.

Current Applications

Continuous communication links with all five continents by means of 24-hour orbit satellites (satellites with an angular velocity equivalent to the angular rotation of the earth) are now possible. Weather forecasts can be obtained as an ensemble, making weather predictions more reliable everywhere. Monitoring of various activities of certain other nations for purpose of national defense is now possible. Maritime and aircraft control anywhere in the world, tracking large concentrations of fishes for alimentary purposes, and continuous monitoring of aircraft flight data to detect and/or predict the malfunction of aircraft systems on long range missions can now be done. A recently discussed application is the use of satellite communications for educational purposes. It would be no surprise to find that one day satellites are used to trace paths of least ice concentration for ice breakers and huge oil tankers travelling from Alaska to the U.S.A. in the North Sea.

Types of Communication Satellites and Links

Some of the major considerations in developing a system of communication satellites involve reliability, high capacity, flexibility, minimum delay and economy [3]. Two types of communication satellites offer advantages and disadvantages based on these objectives. The first type, passive reflectors, is a communication satellite with no active

equipment on board; there is just a reflector on the satellite. The other type, active repeaters, is a communication satellite with active electrical and mechanical equipment, energy being needed for proper functioning of the equipment. A typical basic design of an active communication satellite is shown in Figure 1 [3].

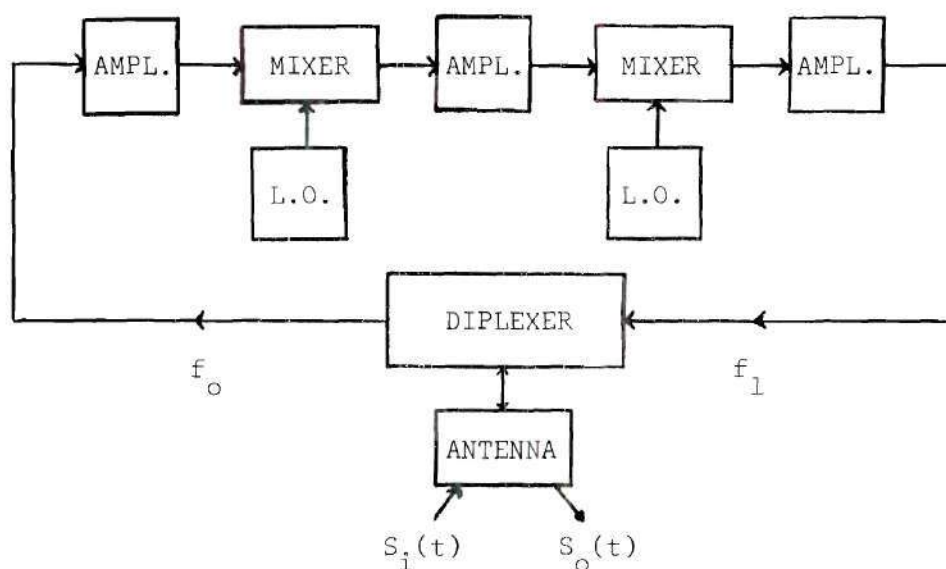


Figure 1. Basic Design of an Active Satellite

The passive reflector satellite offers an inherent reliability and the possibility of being shared by a large number of users operating over a wide range of frequencies. This satellite has the disadvantage that huge reflectors on the satellite, high gain transmitting antennas, high transmitting power, and a substantially greater number of satellites, are required to provide longer range and/or wider coverage. These disadvantages make passive reflectors uneconomical to provide worldwide communications.

Active satellite transmission links offer both greater distance of transmission and higher bandwidth than passive links. The simplest active relay involves the reception of a microwave frequency, say, at the satellite, the translation of the frequency to another frequency without demodulating, and retransmission of the second frequency from the satellite to the user. This was the principle used in Telstar [2].

There are four types of space-communication links [2]. These are: (a) ground to satellite, (b) ground to user via passive reflectors, (c) ground to user via active repeaters, (d) and satellite to satellite. In this thesis ground to user via active satellites is considered.

CHAPTER II

MALFUNCTION DETECTION AND PREDICTION FOR AIRCRAFT

Nature of the Problem

The motivation for this thesis is based on the detection and/or prediction of malfunctions for systems in flight aircraft. Consider Figure 2, which represents a military aircraft on a mission to some destination far away from the ground control facility. It is desired that the ground control facility receive data on subsystems of the aircraft continuously. This data is processed and analyzed so that a decision can be made on the system's condition; for example, a decision whether or not a monitored system is "bad." Obviously, the collection of data to establish the necessary statistical representations involves considerable flight testing. Since the needed facilities were not available for this thesis, it will be assumed that these statistics are available in the following discussion.

The primitive way of solving the malfunction detection and prediction problem for a system on the aircraft involves four of the most important senses, that of sight, hearing, touch and smell. Here the human senses act like a detector and the mind as the decision maker. This is not a reliable way of solving the problem because by the time the malfunction is detected it may be too late for a decision to be made. Some other method capable of detecting and predicting an early malfunction of a system is needed.

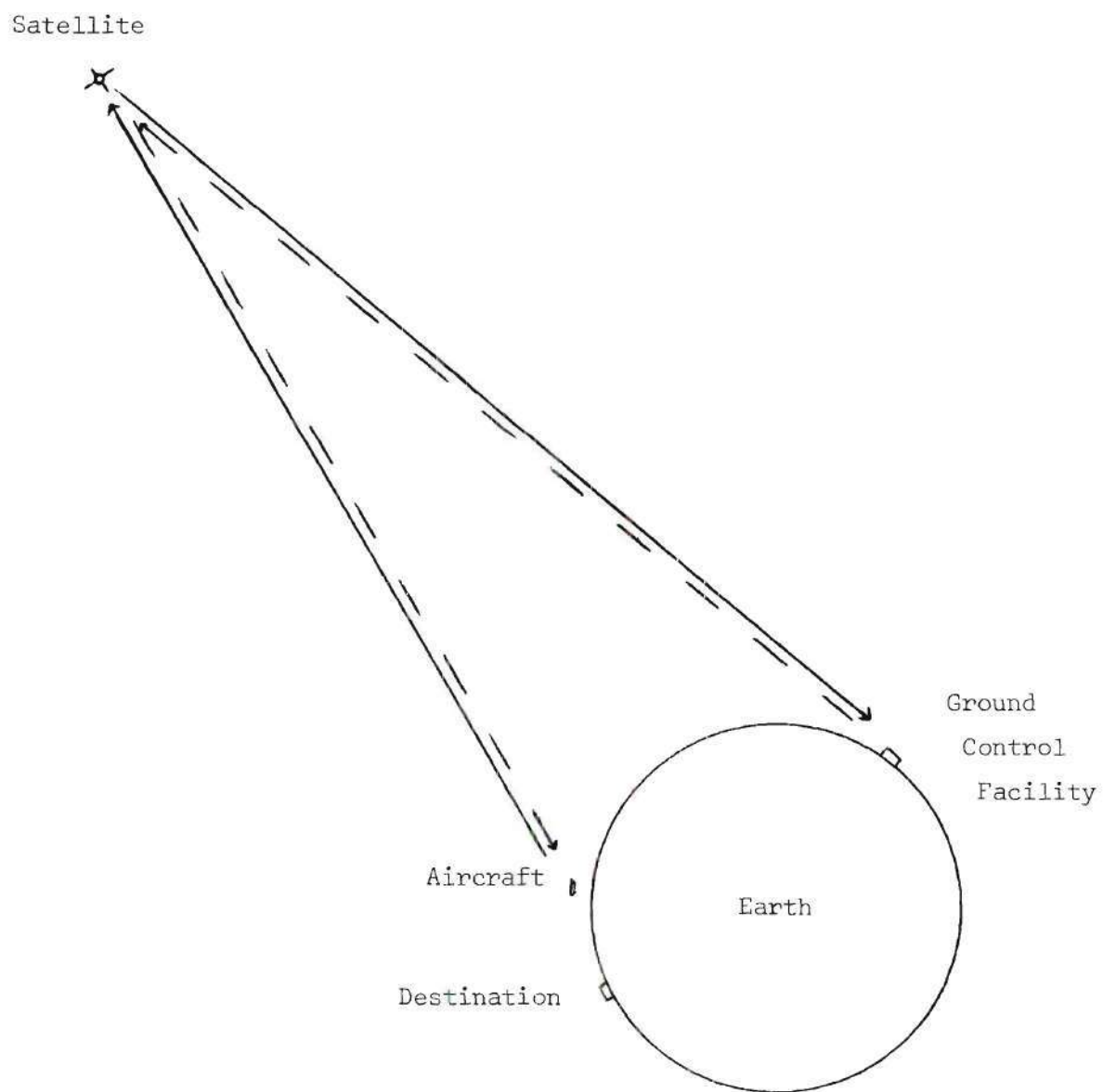


Figure 2. Basic Links

Statistical decision theory can be applied straightforwardly to solve the problem. The detection and prediction of the malfunction is performed at the ground control facility on the basis of data transmitted from the aircraft via satellites.

Decision Theory Approach

An approach to solving the problem of malfunction detection and/or prediction involves the establishment of a decision rule to determine if an aircraft system is "good" or "bad"; i.e. to determine which possible cause of the observed event is most likely. The decision rule is to be determined in advance from knowledge of the causes and their connections with the two events that can occur. This knowledge is expressed in the form of given probability density functions conditioned on the two hypotheses [4]. To obtain these functions could require the gathering of large amounts of statistical information from "good" and "bad" systems. This step is of course extremely important, but for this thesis there were no available facilities for this preliminary statistical characterization. Here we discuss the problem from the point of view that these data are known.

The approach used in this malfunction detection is to fix a decision threshold η and from the conditional densities of the system compare the ratio of the conditional densities of the system called the likelihood ratio, to the threshold η . If the likelihood ratio $\Lambda(\underline{R})$ is equal to or greater than η decide "system is good" and if $\Lambda(\underline{R})$ is less than η decide "system is bad" (see Figure 3). If H_1 represents the hypothesis that the "system is good," then the observation r_g should

be equal to the data signal received of a "good system"; then H_0 represents the hypothesis that the "system is bad," and the observation r_0 should be equal to the data signal received of a "bad system"; i.e.

$$H_1: \quad r_g = g \quad (1)$$

$$H_0: \quad r_b = b$$

The Likelihood Ratio (LRT) is [5]

$$\Lambda(\underline{R}) = \frac{p(\underline{R}/H_1)}{p(\underline{R}/H_0)} \quad (2)$$

and

$$\eta = \frac{P_o(C_{10} - C_{00})}{P_1(C_{01} - C_{11})} \quad (3)$$

where \underline{R} = observation vector (r_1, r_2, \dots, r_n)

$\Lambda(\underline{R})$ = likelihood ratio

$p(\underline{R}/H_1)$ = probability density that the observation \underline{R} is assigned to r_g and consequently H_1 is actually true

$p(\underline{R}/H_0)$ = probability density that the observation \underline{R} is assigned to r_b and H_0 is actually true

P_o = the a-priori probability that r_b is observed

P_1 = the a-priori probability that r_g is observed

C_{00} = cost assigned for saying that H_0 is true when it is

C_{10} = cost assigned for saying that H_1 is true when it is not

C_{01} = cost assigned for saying that H_0 is true when it is not

C_{11} = cost assigned for saying that H_1 is true when it is.

The Likelihood Ratio Test (LRT) becomes

$$\Lambda(\underline{R}) \begin{matrix} H_1 \\ \geq \eta \\ H_0 \end{matrix} \quad (4)$$

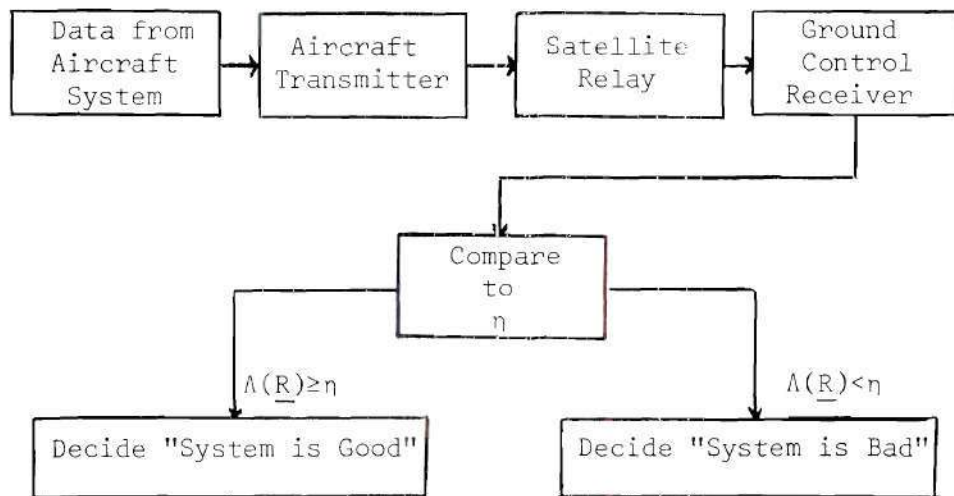


Figure 3. Basic Detection Schematic

Equation (4) represents Bayes decision rule. All the data processing is involved in computing $\Lambda(\underline{R})$; $\Lambda(\underline{R})$ is not affected by a-priori probabilities or cost assignments as can be seen in Equations (2) and (3), but η is.

Suppose two stationary random signals r_1 and r_0 are such that

$$H_1: \quad r_1 = g(t_1) \text{ with a-priori probability } P_1 = \frac{1}{2}$$

$$H_0: \quad r_0 = b(t_1) \text{ with a-priori probability } P_0 = \frac{1}{2}$$

let us assume that the probability density of a "good system" is Figure 4 and that of a "bad system" is Figure 5.

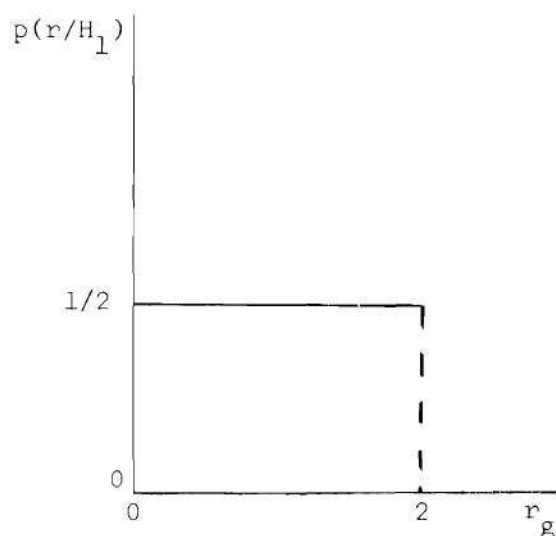


Figure 4. "Good System"
Probability Density

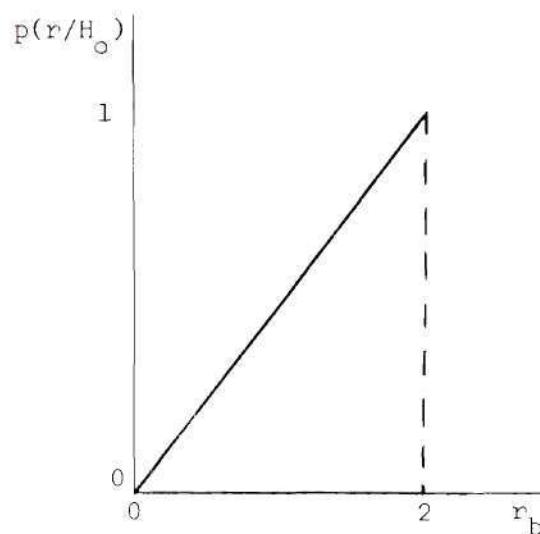
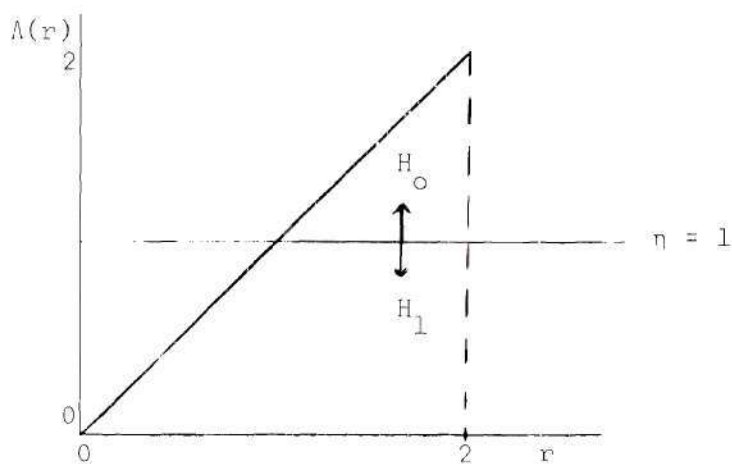


Figure 5. "Bad System"
Probability Density

We want to find Bayes decision rule and the total probability of error.
The likelihood ratio becomes (see Figure 6)

$$\Lambda(r) = \frac{p(r/H_0)}{p(r/H_1)} = \frac{(1/2)r}{1/2} = r, \quad 0 \leq r \leq 2$$

Figure 6. Likelihood Ratio $\Lambda(r)$

and the threshold η is

$$\eta = \frac{(1/2)(1-0)}{(1/2)(1-0)} = 1$$

assuming $C_{10} = C_{01} = 1$ and $C_{00} = C_{11} = 0$, the likelihood ratio becomes

$$\Lambda(r) \begin{matrix} H_0 \\ \geq \\ < \\ H_1 \end{matrix} 1$$

and Bayes decision rule becomes (see Figure 7)



Figure 7. Bayes Decision Rule for Single Sample

The probability of error is written as

$$P(\text{error}) = P_0 P(H_1/H_0) + P_1 P(H_0/H_1) \quad (5)$$

but

$$P(H_1/H_0) = \int_0^1 p(r/H_0) dr = \int_0^1 1/2 r dr = 0.25$$

and

$$P(H_0/H_1) = \int_1^2 p(r/H_1) dr = \int_1^2 1/2 dr = 0.50$$

therefore

$$P(\text{error}) = 1/2 (0.25) + 1/2 (0.50) = 0.375$$

From Figure 7 it is seen that if the sample falls between 0 and 1 ($0 < r < 1$) then it is decided that "the system is good" (H_1) and if the sample falls between 1 and 2 ($1 \leq r \leq 2$) decide "the system is bad" (H_0).

Suppose now that two stationary random signals r_1 , r_0 are such that

$$H_1: r_1 = g(t)$$

$$H_0: r_0 = b(t)$$

Two statistically independent samples r_1 , r_0 of one of these waveforms are taken at $t=1$ and $t=2$.

$(r_1, r_o) = (b(1), b(2))$ with a-priori probability $P_o = 1/2$

$(r_1, r_o) = (g(1), g(2))$ with a-priori probability $P_1 = 1/2$

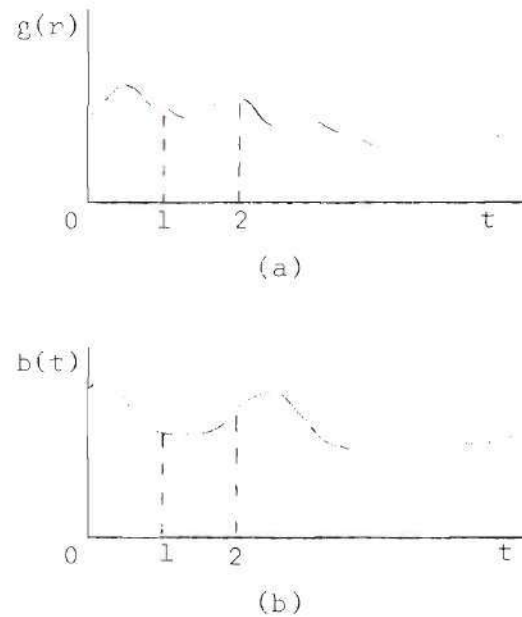


Figure 8. Two Signals and Two Samples

We want Bayes' decision rule and the total probability of error. The probability densities of a "good" and "bad" system are the same as in Figures 4 and 5.

The likelihood ratio becomes (see Figure 9)

$$\Lambda(\underline{R}) = \frac{p(r_1, r_o/H_o)}{p(r_1, r_o/H_1)} = \frac{p(r_1/H_o) p(r_o/H_o)}{p(r_1/H_1) p(r_o/H_1)}$$

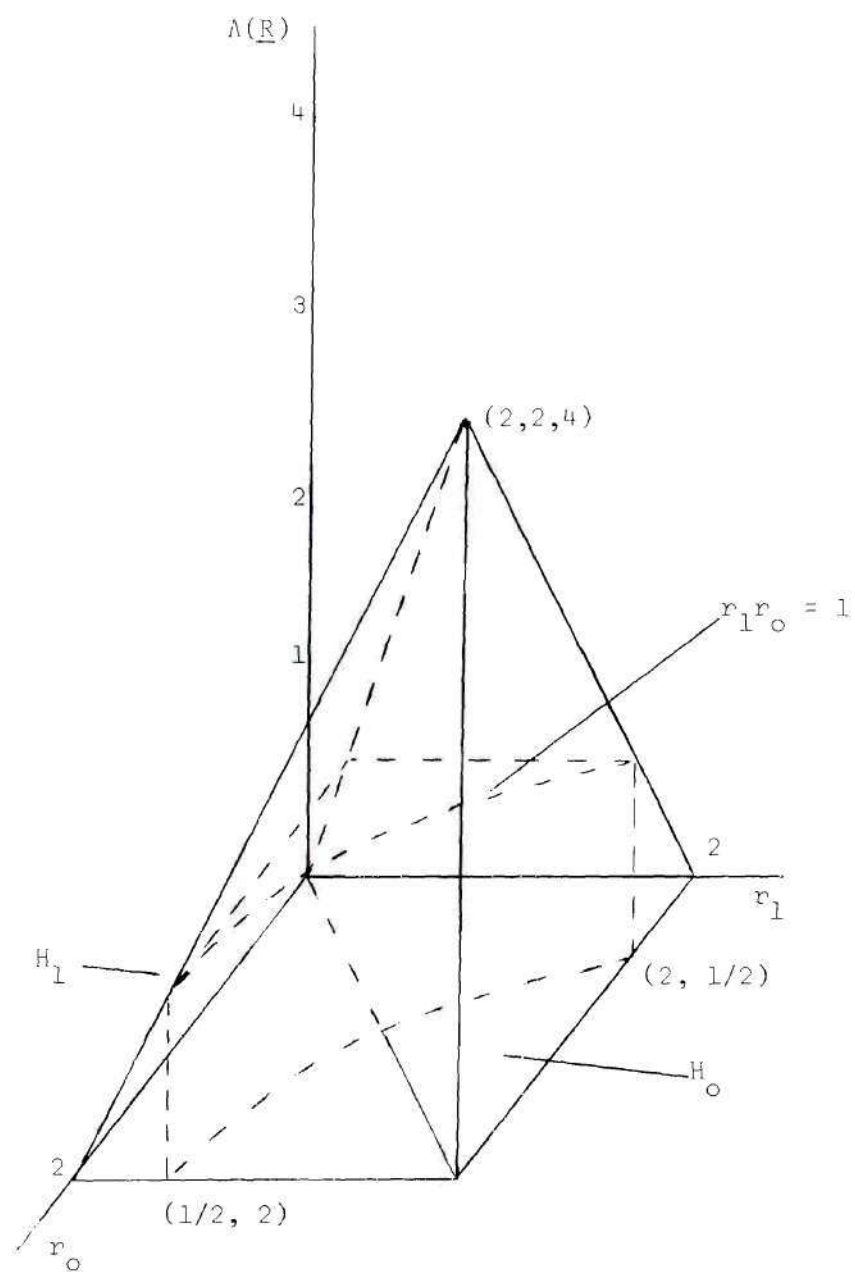


Figure 9. Likelihood Ratio $\Lambda(\underline{R})$

$$= \frac{(1/2 r_1)(1/2 r_o)}{(1/2)(1/2)} = r_1 r_o, \quad \begin{array}{l} 0 \leq r_1 \leq 2 \\ 0 \leq r_o \leq 2 \end{array}$$

The threshold η is the same as in the previous illustration, i.e. $\eta = 1$.

The LRT becomes

$$\Lambda(\underline{R}) \underset{H_1}{\overset{H_o}{\geq}} 1$$

and Bayes decision rule is Figure 10.

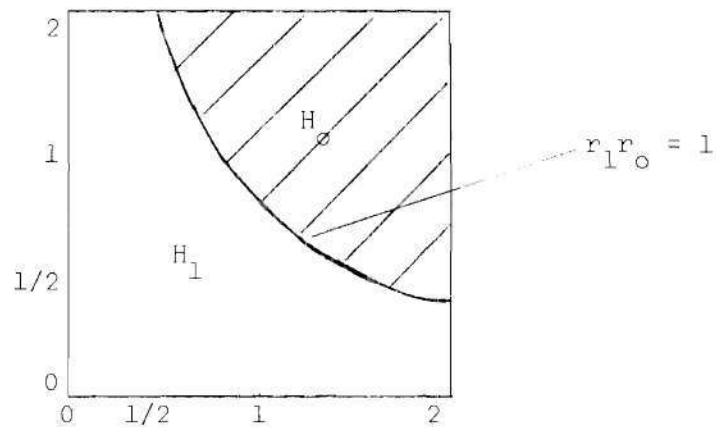


Figure 10. Bayes Decision Rule for Double Sample Case

The probability of error defined as in Equation (5) for

$$\begin{aligned}
 P(H_0/H_0) &= \int_{1/2}^2 \int_{1/r_1}^2 p(R/H_0) dr_1 dr_0 - \int_{1/2}^2 \int_{1/r_1}^2 1/4 r_1 r_0 dr_1 dr_0 \\
 &= 0.763
 \end{aligned}$$

but

$$P(H_1/H_0) = 1 - P(H_0/H_0) = 0.237$$

and

$$\begin{aligned}
 P(H_0/H_1) &= \int_{1/2}^2 \int_{1/r_1}^2 p(R/H_1) dr_1 dr_0 = \int_{1/2}^2 \int_{1/r_1}^2 1/4 dr_1 dr_0 \\
 &= 0.406
 \end{aligned}$$

Therefore

$$P(\text{error}) = (1/2)(0.237) + (1/2)(0.406) = 0.3215$$

As more samples are taken for the decision the total probability of error is decreased. Given the probability densities of the systems, the threshold, and the number of samples, the decision is made by making use of the LRT.

Prediction theory as used here is similar to detection theory. The prediction that a "good system" is going "bad" within a time period is solved similarly to the detection problem. The probability densities of a "system going bad" and "system not going bad" have to be known; the rest follows similarly to the decision theory previously mentioned. Prediction whether a "bad system will get worse, stay as it is, or

become normal" can be handled similarly. The probability density of a "bad system staying as it is," of a "bad system getting worse," and of a "bad system becoming good" would have to be determined from previously collected data. Thus decision theory as applied to M-hypotheses may play a role.

CHAPTER III

SYSTEM DESIGN

Use of Satellites

Everyday communication is mostly done on line-of-sight links. The distance involved between the two communicating stations is so small that conventional communication systems will be sufficient for the purpose. An example is the reception of the signal from a local station on the standard AM radio. The loudness (clearness) of the received signal is a function of many parameters; for example, the distance from the transmitting station to the receiving station, the type of antennas used, the type of modulation used, noise and interference levels, the quality of the systems involved, etc. For data transmission between two relatively near points on the earth surface where efficient communication may be important, the modulation method strongly affects this efficiency; choice of the modulation method involves tradeoffs between performance desired and system complexity and cost.

In the last ten years there has been so much progress in solid state electronics that uninterrupted long range communication through the air is now possible. Not so long ago, the only means of communication between Europe and America was through an underwater coaxial cable. With the progress of electronics, it is now possible to design a system capable of delivering a large amount of power from a small and

light-weight system. This has brought about the satellite as a communication relay.

Satellite communication has brought revolutionary changes. It is now possible to design systems which were only dreamed of before. At first satellite communication was used for defense purposes; now it also provides a means of obtaining more knowledge of our universe and can bring about improvement of man's standard of living.

There are certain limiting factors in satellite communications. The most important parameters to consider in satellite communications are: effective radiated power (ERP), weight, available energy, and cost.

The ERP, defined as

$$\text{ERP} = P_t G \quad (6)$$

and

$$G = (E_1/E_o)^2 \quad (7)$$

where P_t = transmitted power

G = power gain of the antenna

$\frac{E_1}{E_o}$ = the ratio of the radiated field in the maximum beam of the antenna to the radiated field at the same frequency and power of an isotropic antenna.

is a function of the power received by the satellite. To obtain a certain power received by the terminal receiver it is necessary that the

satellite supplies an additional power equivalent to the difference between ERP and the power received by the satellite receiver PRS. Assuming the satellite and terminal receivers have isotropic (unit gain) antennas, the free space loss, L_o , defined as the ratio of the energy received to that transmitted, is found to be for direct line-of-sight links

$$L_o \text{ (DBW)} = 37 + 20 \text{ Log}(f) + 20 \text{ Log}(d) \quad (8)$$

where d is the distance between the transmitter and the receiver in miles and f is the transmitting frequency in Mc [2]. The power received at the ground station would then be

$$PRG = ERP - L_o \quad (9)$$

As far as space communication is concerned, the problem of providing sufficient energy may be divided between the amount of energy available in the space vehicle (satellite and aircraft), the degree to which that energy can be directed toward the receiver, and the efficiency of the receiving system in detecting this energy in the presence of noise. In the satellite and the aircraft, both the transmitted power and the total available energy are important parameters. The effective power available may be increased 1) by increasing the transmitter power, 2) by increasing the transmitter efficiency, or 3) by increasing the antenna gain. All of these are functions of both weight and cost.

To increase transmitter power, it is necessary to provide a larger source, larger components, and heavier and more complex temperature control mechanisms. Each of these results in an almost linear increase in payload weight with increasing power.

Efficiency is a function of the method of modulation. The maximum amount of information which can be transmitted in a channel is a function of the radio frequency bandwidth, B , and the signal-to-noise ratio, SNR, at the receiver. The probability of error, P_e (the probability that a data bit H_i is received when H_j was sent) is a function of the SNR and of the modulation used.

For satellite communications, the most efficient system is some form of pulse code modulation (PCM).

The antenna gain is a function of weight and transmitting frequency. For a given antenna weight, the transmitting antenna gain increases as the frequency increases. Choosing a high frequency for a given antenna gain would greatly decrease the weight of the satellite and of the aircraft's antenna [1]. The frequency cannot be too high because the free space losses would be too high. Some tradeoff must be made in either case.

Speed, Position, and Tracking System

"Speed, position, and tracking" (SPOT) is a proposed surveillance and navigation system which may be in operation by 1975 [6]. Due to the extremely large coverage area which lies within direct line-of-sight of satellites, particularly at synchronous attitude, satellites will be used as platforms for navigation and communication. RF signals

transmitted or relayed from such platforms to the surface of the earth or an aircraft, can operate at higher frequencies and be less affected by atmospheric and ionospheric environments than ground based navigation systems. SPOT is a satellite ranging technique which utilizes phase difference measurements. Accurate detection of the noisy signal received at the ground station is important for this system to give reliable results.

It would be of interest to apply the SPOT concept to the problem described in this thesis. The commander of the aircraft can be provided with enough information for the decision (continue flying or land immediately) to be made; or the decision may be made by the ground controller.

The principle involved in SPOT is the following: a ground station continuously transmits an RF signal. The frequency is frequency shifted at satellite A and transmitted to the aircraft (see Figure 11). At the aircraft the signal is retransmitted to satellites A and B; the signal is frequency shifted and transmitted to the ground station. At the ground station the phase differences between the original signal transmitted and the incoming signals are determined. After determining the phase of each incoming signal the distance of the satellites to the aircraft is obtained (assuming that the exact location of the satellites with respect to the ground station is known). By connecting the points of equal phase in the aircraft field a surface of a sphere is generated with the satellite at the center. The intersection of this sphere with the surface of the earth (another sphere) gives a circle (see Appendix

I). The same thing is done with the other satellite; in this way two circles are obtained. The intersection of the two circles gives two possible positions; knowledge of which hemisphere (northern or southern) the aircraft is flying eliminates one of these points.

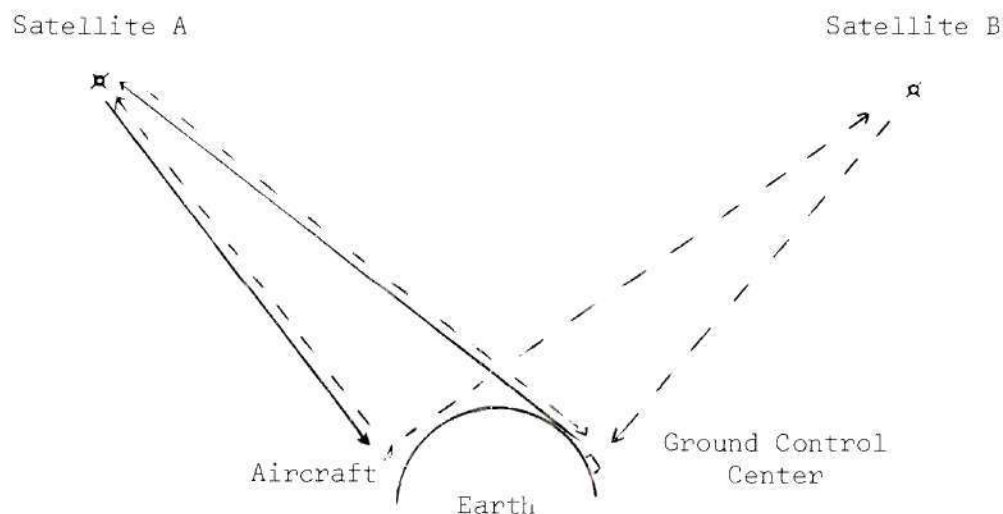


Figure 11. Links Necessary for Determination of SPOT

The SPOT concept is of interest on a worldwide basis; for this, SPOT fulfills this requirement if five 24-hour (synchronous orbit) satellites are used as shown in Figure 12 (see Appendix I). The satellites are placed on an equatorial orbit, thus covering the entire earth except the extreme polar regions.

The speed of the aircraft can be determined by transmitting at $t = T_0$ and $t = T_1$ to one of the satellites from the ground control and obtaining the phase of each message by the SPOT concept mentioned

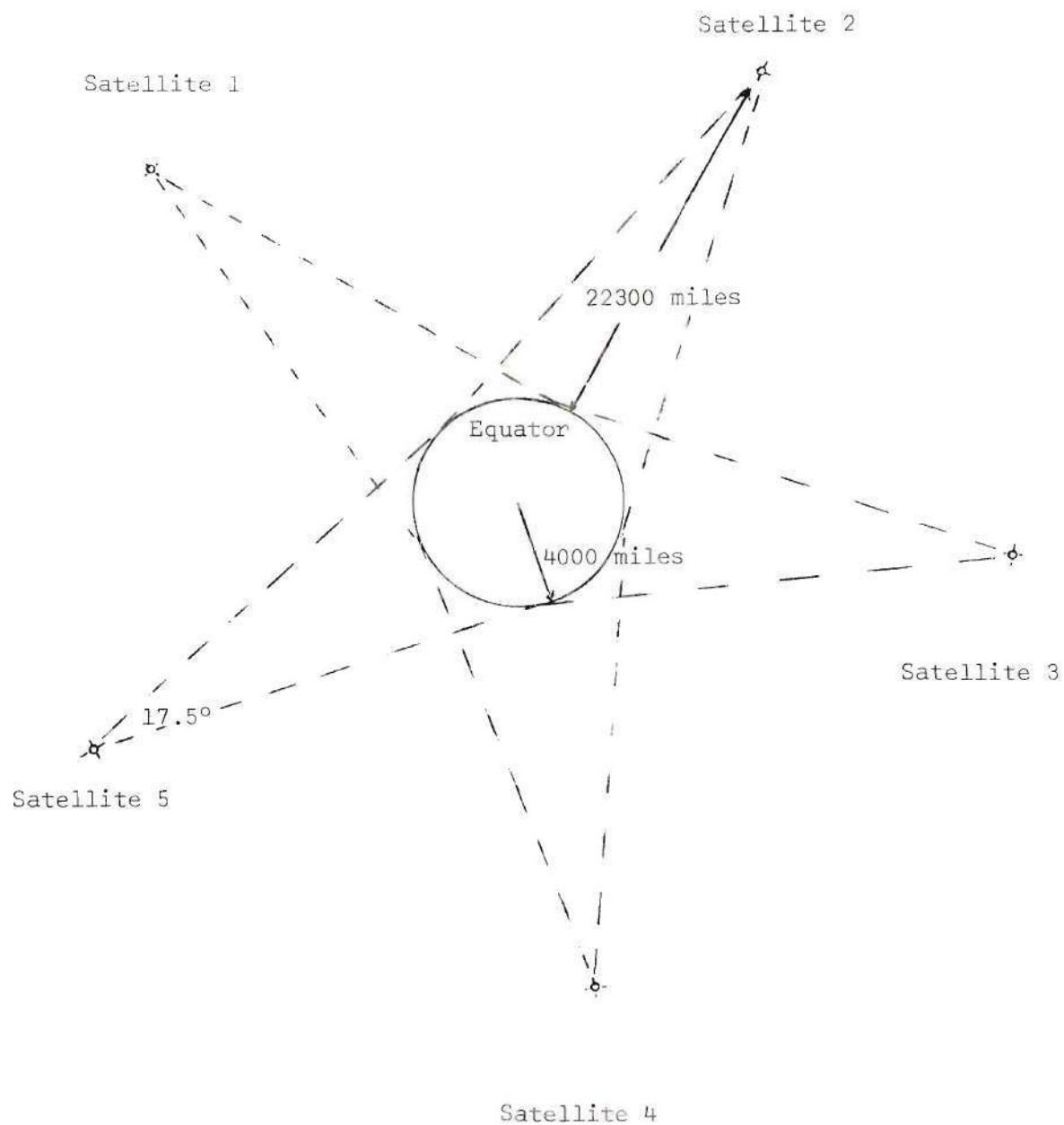


Figure 12. Satellite Orbit and Total Number of Satellites for Worldwide Coverage

earlier. The distance travelled is then known, and, knowing T_1 and T_0 , the velocity can be obtained.

This SPOT concept mentioned earlier will give the position of the aircraft on the earth's surface (if the earth is used as the reference sphere). A way to obtain the altitude of the airplane is by use of a third satellite; the sphere obtained from this satellite is used in place of the earth. Since the altitude of the aircraft is a small distance compared to the large distances the data travel, precise phase measurements are essential. This is hard to achieve; altitude determination is ruled out then.

The type of modulation to be used for SPOT will be the same as the one used in the final system design. Figure 13 illustrates links necessary in SPOT. Figure 14 shows a typical coherent receiver to demodulate the message and detect the phase difference between the incoming and outgoing signal.

The Use of Pseudo Random Codes for Ground-Aircraft, Aircraft-Ground Communication

The detection and prediction, as well as SPOT, cannot be done without the transmission of data from the aircraft to the ground station and vice versa. Data are transmitted from the aircraft to the ground station. The best way of transmitting this data is to be chosen.

For satellite communication a form of pulse code modulation (PCM) is the digital signalling method that gives the best performance. A performance parameter dependent on the type of modulation must be found so a basis for comparison can be established. Many communication

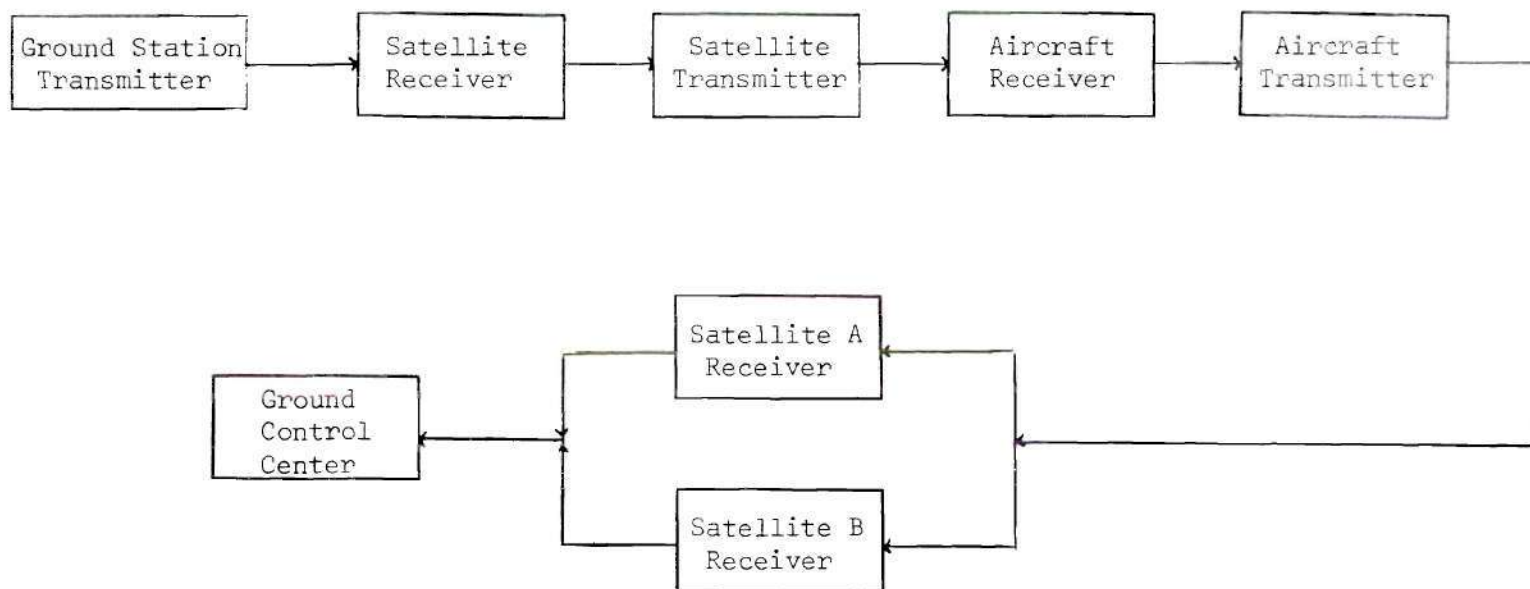


Figure 13. Sample Link Block Diagram

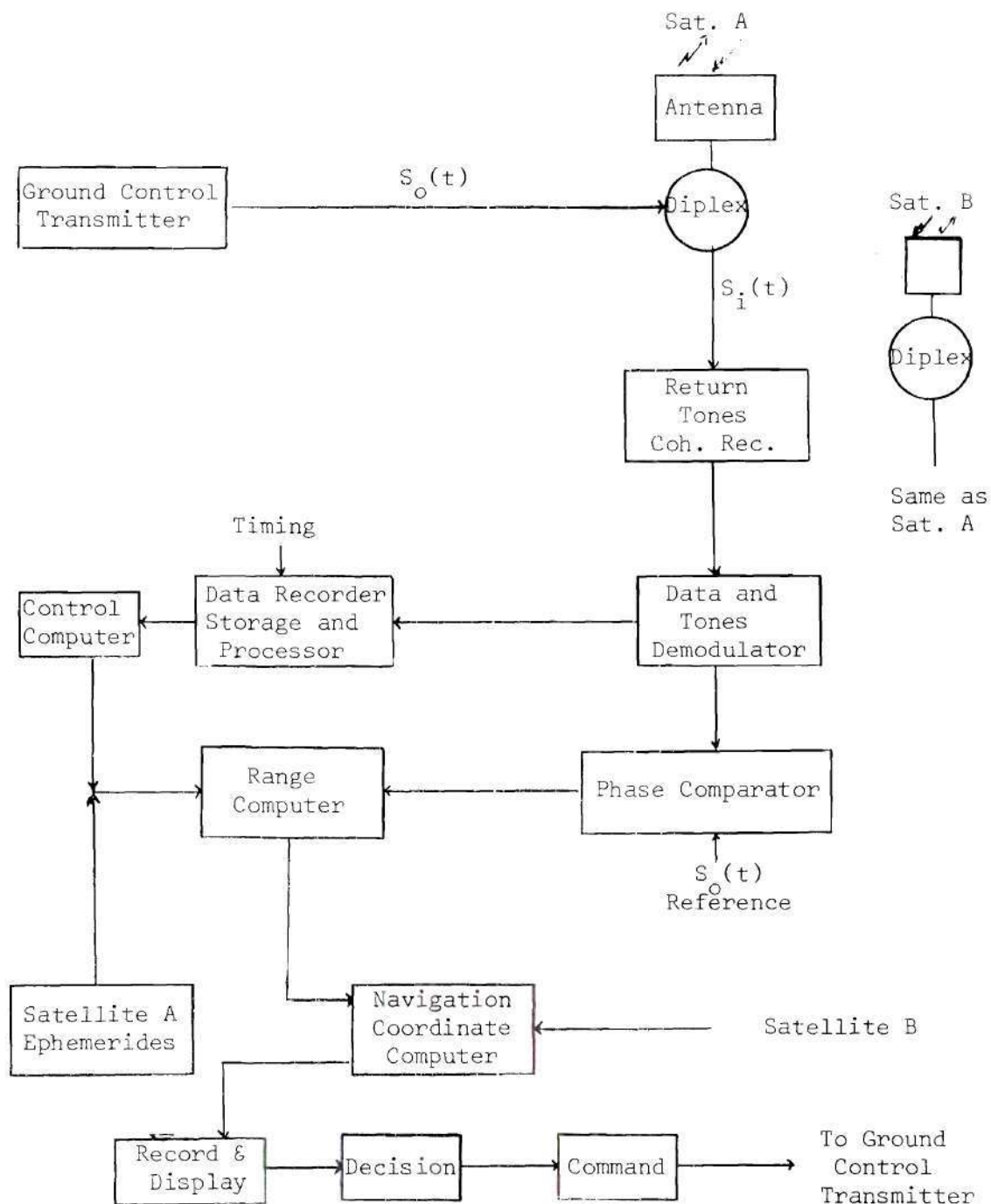


Figure 14. Typical SPOT Receiver

engineers use probability of error, P_e , and signal-to-noise ratio, SNR, as the parameters. A modulation technique that gives the least probability of error for a given SNR must be chosen; some kind of pulse code modulation will be used.

For perfect synchronization and Coherent Phase Shift Keying (CPSK), the SNR at the receiver input for a data bit probability of error of 0.001 is 6.4 db, compared to 9.4 db for Coherent Frequency Shift Keying (CFSK) [7]. Under the assumptions that the optimum threshold is used in the receiver, the noise is a narrow-band zero-mean Gaussian process, and all signals are equally likely, CPSK is 3 db better than CFSK. Continuous waveform modulations will not be considered because their performance is not as good in the presence of noise. Digital communication gives better performance under this condition.

In satellite communication the noise level is very high. The high noise levels present a problem in itself when ideal synchronization between the outgoing and incoming signal is the ultimate goal.

There is a family of binary codes which is characterized by a two level autocorrelation property. A code of period $L = 2^n - 1$ having the above-mentioned characteristic and the cycle-and-add property exists; this code is often referred to as maximal length shift register pseudo random or pseudo noise (PN) codes [8]. Use of such codes may allow an improvement on the performance of CPSK modulation.

The cycle-and-add property in PN codes has the characteristic that given a PN code of period $2^n - 1$ and any cyclic permutation of the

same PN code, the modulo 2 (mod 2) sum is another cyclic permutation of the PN code [9].

PN codes have the autocorrelation and cross-correlation defined as

$$A(k) = \sum_{i=1}^L (PN_1)_i \oplus (PN_1)_{i+k} \quad (10)$$

$$C(k) = \sum_{i=1}^L (PN_1)_i \oplus (PN_2)_{i+k} \quad (11)$$

where \oplus = mod 2 addition

PN_1 = a PN code of period L_1

PN_2 = another PN code of period L_2 ,

respectively. Figures 15 and 16 show the autocorrelation and cross-correlation functions, respectively. The greater the length of the PN codes the better the autocorrelation and crosscorrelation [9]. Two PN codes are perfectly synchronized if $C(0) = C(L_1 L_2) = \dots = C(nL_1 L_2) = 0$, $n = 0, 1, 2, \dots, N$; if this is not the case, then perfect synchronization can be almost achieved by means of a phase-locked loop as long as k is between $\{n(L_1 L_2 - 1/2), n(L_1 L_2 + 1/2)\}$ for $n = 0, 1, 2, \dots, N$.

If PN codes are used with CPSK modulation, the signal-to-noise ratio for a P_e of 10^{-3} with perfect synchronization is 6.82 db. However, perfect synchronization (infinite PN code period) cannot be achieved in the presence of noise; under this condition CPSK-PN gives a better SNR than CPSK [10].

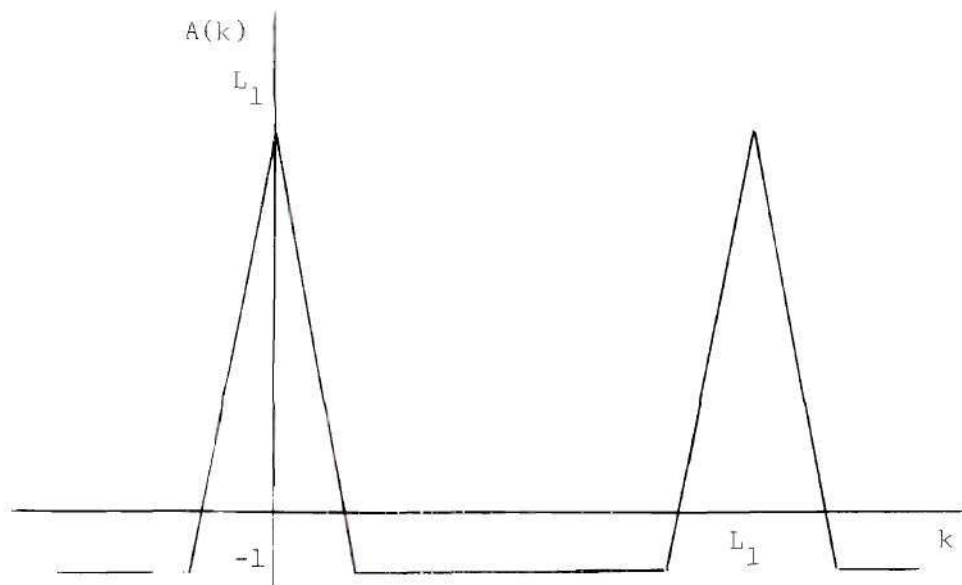


Figure 15. Autocorrelation of PN Code

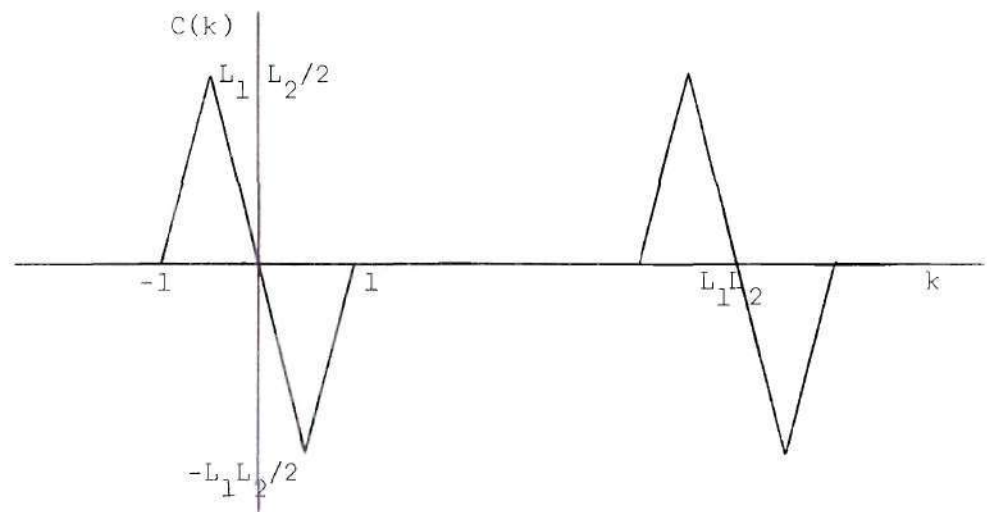


Figure 16. Crosscorrelation of PN Codes

The best link for this design is a combination of super-high frequency (SHF) and ultra-high frequency (UHF) [11]. Other links have been studied and the choice was narrowed to UHF-UHF and UHF-SHF (see Figure 17).

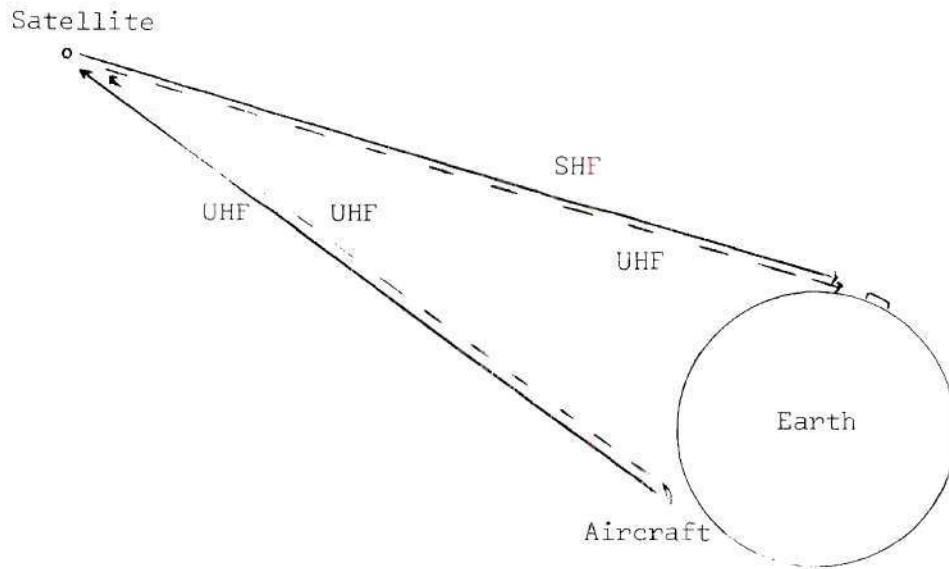


Figure 17. UHF-SHF and UHF-UHF Links

The signal-to-noise ratio for CPSK-PN system is

$$\text{SNR} = \frac{\frac{P_r}{N_o} T (P_i/P_t)}{\frac{P_r}{B N_o} a + \frac{B N_w}{P_t} + \frac{P_t - P_i}{P_t} + \left(1 + \frac{b P_r}{B N_o}\right) \left(1 + a + \frac{B N_w}{P_t}\right)} \quad (12)$$

where P_r = power from satellite received by terminal

where P_i = power received by satellite from i th transmitter

$$P_t = \sum_{i=1}^k P_i = \text{total signal power at satellite receiver}$$

N_o = effective noise power density of terminal receiver

N_w = effective noise power density of satellite receiver

B = total RF bandwidth

T = integration time per message waveform

a = ratio of noise power in satellite receiver due to interference with the total signal power at the satellite receiver

b = ratio of noise power in terminal receiver due to interference with the total signal power at terminal receiver

SNR = signal-to-noise at the output of i th receiver

The link limiting the performance of the transmission system is the aircraft-ground link. Since the transmitter at the ground station can transmit an ERP large enough to overcome satellite receiver noise, the ground-aircraft link will give a better performance than the aircraft-ground link.

Figure 18 illustrates how SNR depends on the parameter

$$\rho \left(\rho = \frac{B N_w}{P_t} \right); \text{ the } \rho \text{ that gives the best SNR is used to obtain an optimum}$$

RF bandwidth for a given N_w and P_t . Table 1 shows some of the design parameters obtained for the UHF-UHF and UHF-SHF links (see Appendix 2); from this table it is seen that (for the case where the power received at the ground receiver is the same as the power received at the satellite receiver ($P_r = P_t$)) UHF-SHF link gives the lowest power required for the

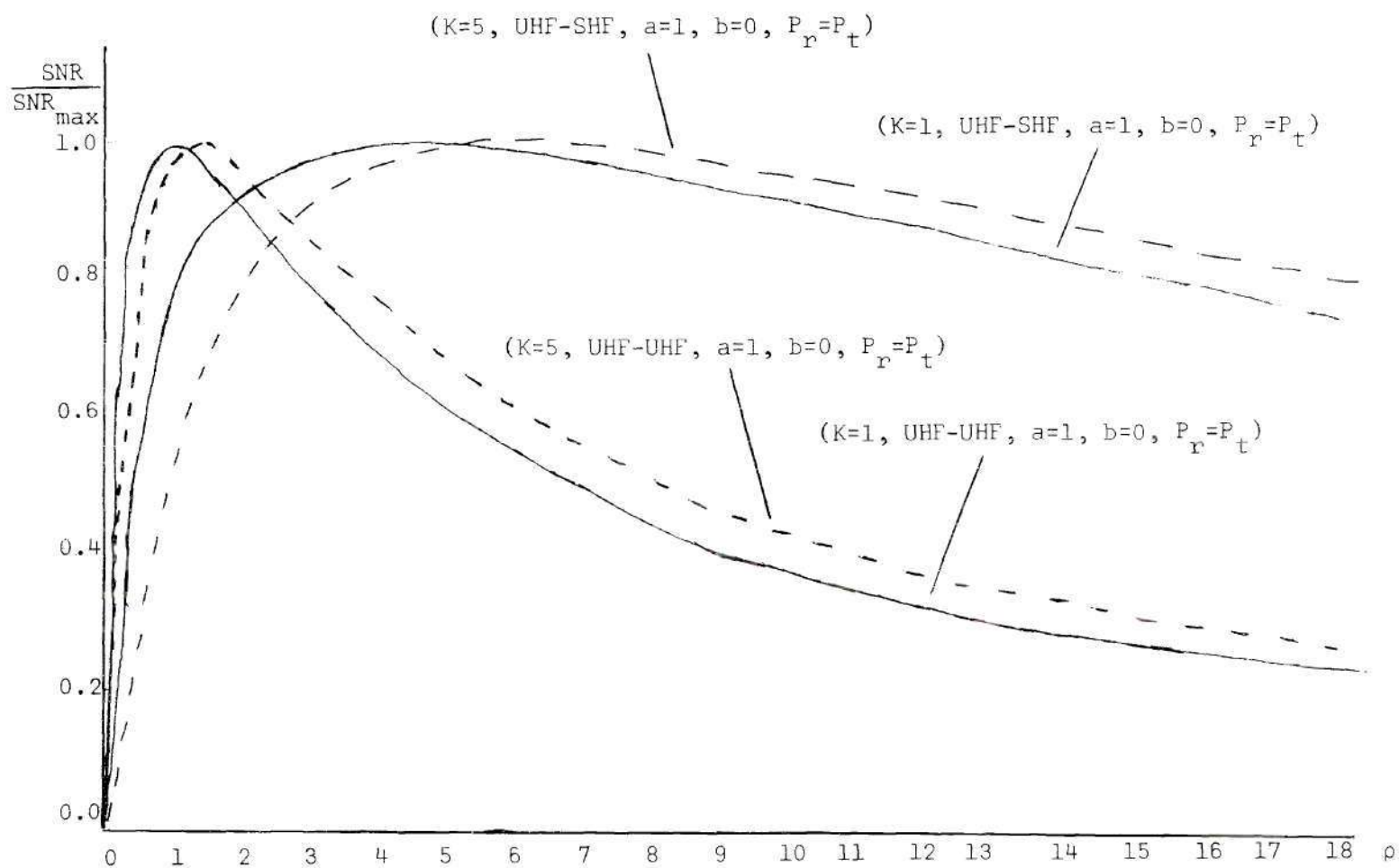


Figure 18. SNR_n Versus RF Bandwidth $\left(\rho = \frac{B N_w}{P_t} \right)$.

Table 1. Design Parameters for UHF-UHF and UHF-SHF Links

Link Type	P_r/P_t	No. of Channels	ERP of Satellite (DBW)	ERP of Aircraft (DBW)	Total Power Received at Satellite (DBW)	Power at Ground Receiver (DBW)	RF Band- width (MHz)
UHF-SHF	100	5	44.5	-336	-151	-131	7.64
		1	45.3	-336	-152	-132	5.48
	1	5	26.5	-334	-149	-149	1.20
		1	26.0	-334	-150	-150	0.80
	0.01	5	16.5	-324	-139	-159	1.20
		1	16.0	-324	-140	-160	0.80
UHF-UHF	100	5	45.3	-335	-151	-131	2.02
		1	45.0	-335	-151	-131	1.41
	1	5	31.8	-329	-144	-144	0.90
		1	31.2	-329	-145	-145	0.58
	0.01	5	27.9	-313	-128	-148	3.70
		1	27.6	-313	-128	-148	2.58

aircraft and satellite receivers as well as a lower ERP transmitted by the aircraft transmitter; this means a great reduction in satellite size and a large savings in weight on both the aircraft and the satellite.

Multiplexing will be necessary in the design to have several channels available. For a data rate of 2400 bits/sec Time Division Multiplexing (TDM) can be used (see Appendix 2); Code Division Multiplexing (CDM) and Frequency Division Multiplexing (FDM) are not ruled out. TDM has a 2 db advantage over CDM for high channel activity factor. If a 25 per cent voice channel activity factor is assumed, then CDM has at least a 4 db advantage over the two other types of multiplexing [11]; this suggests then that CDM is suitable for the ground-aircraft link and TDM is suitable for the aircraft-ground link.

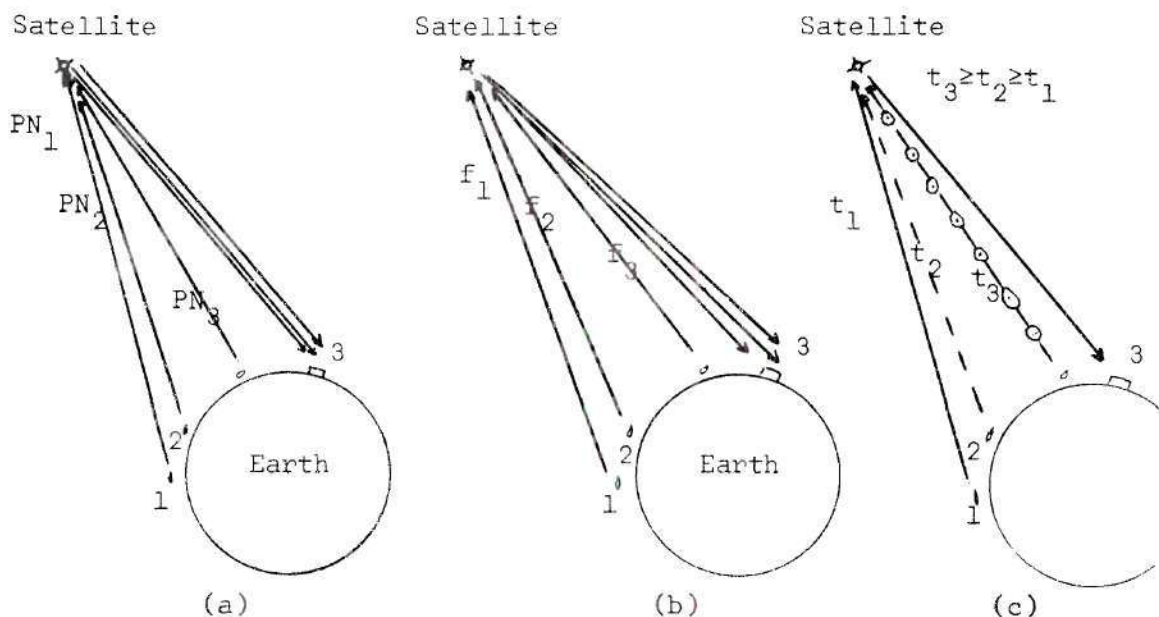


Figure 19. CPSK-PN Links with: (a) CDM; (b) FDM; (c) TDM

Final System Design

Modulation techniques were discussed earlier and it was pointed out that CPSK requires an input signal-to-noise ratio of 6.4 db compared to 6.82 db for CPSK-PN with perfect synchronization for a bit probability of error of 10^{-3} . The practical difficulty in CPSK lies in obtaining the necessary bit synchronization to know where a bit begins and in obtaining the coherent demodulation reference within the detector with accuracy and stability. If bit synchronization timing is inaccurate then sampling may take place too soon or too late, thereby reducing the probability of making the correct decision. In the presence of noise, bit synchronozation becomes very difficult since the reference signal then is not noise free (see Figure 20).

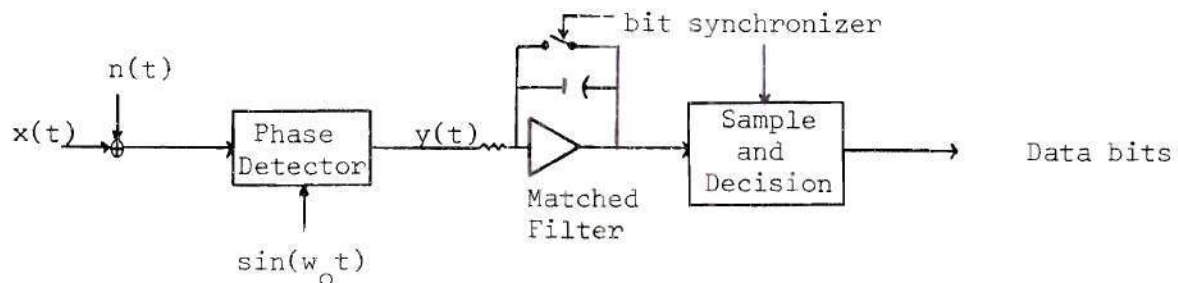


Figure 20. Basic CPSK Receiver [9]

where $x(t) = \pm \sin(w_o t + \theta)$

$y(t) = \pm 1/2[\cos\theta - \cos(2w_o t + \theta)] + \text{noise}$

In addition to bit synchronization, word synchronization to separate the detected data bits into the proper groups to get the correct word is necessary. The amount of energy required to establish good synchronization can be significant; if part of the transmitter energy is used to obtain synchronization, this requires that the transmitter energy be larger by this amount.

The use of binary codes to achieve bit and word synchronization is possible. Here it is the function of the detection and decoding equipment to obtain, by means of correlation techniques, the correct code patterns. To achieve bit and word synchronization within a reasonable amount of time the decoding equipment may be as complex as a digital computer. The use of maximal-length linear shift register codes with phase lock techniques to obtain bit and word synchronization as well as a coherent demodulation reference permit the detection and decoding equipment to obtain the correct code patterns. Because of correlation properties of PN codes, the longer the code period the better the correlation (see page 33).

A typical UHF CPSK-PN transmitter is shown in Figure 21. The PN code generator clock is $2f_s$ and it is defined such that

$$2f_s = f_s \oplus \underline{f_s/90^\circ}$$

A typical CPSK-PN ground receiver channel is shown in Figure 22 [11]. Two phase locked loops are needed, one for tracking the RF carrier and one for tracking the PN clock. The digital data signal output

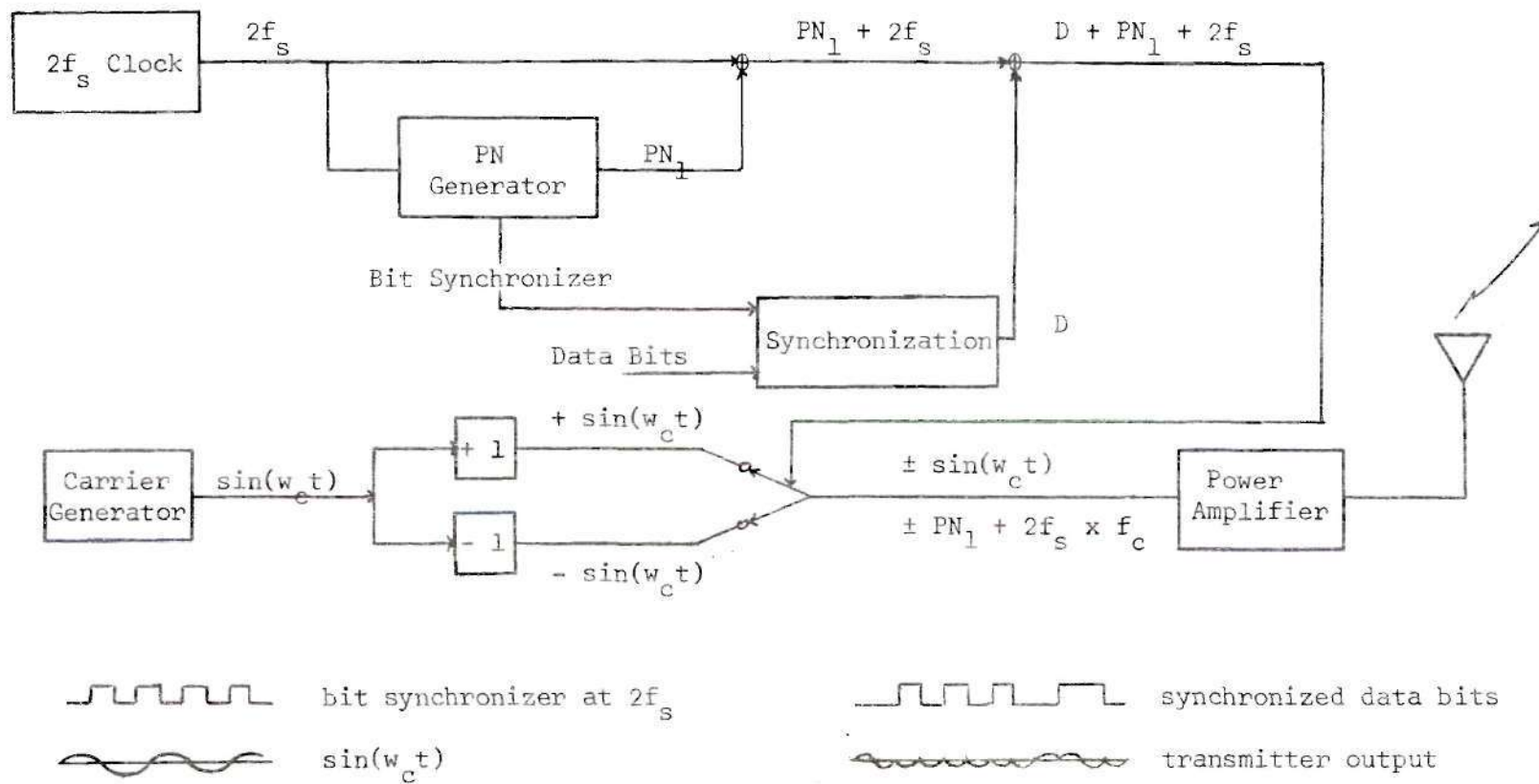


Figure 21. Basic CPSK PN Transmitter [9]

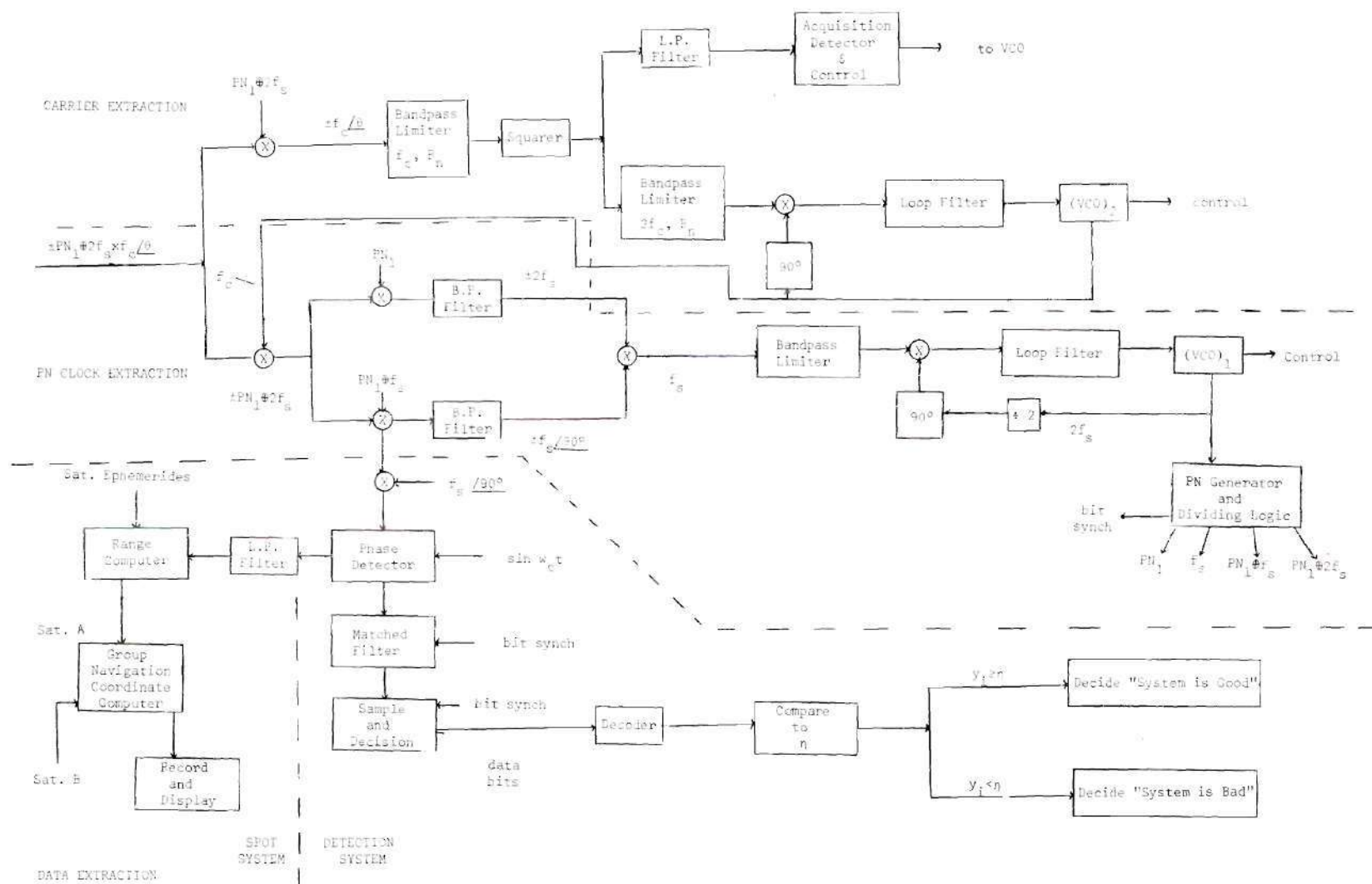


Figure 22. Typical CPSK-PN Ground Receiver [11]

is taken from the CPSK demodulator and data recovery circuits. The input to the PN loop is the modulo-2 addition of the clock and the PN signal; this signal is fed into two mixers, one accepts PN as a reference input and the other $PN \oplus 2f_s$. The output of one of the mixers is $2f_s$ and the other is $f_s / 90^\circ$. These components are filtered and then fed into another mixer where the PN clock frequency f_s is extracted. A phase locked loop then tracks the PN signal. The phase needed for the SPOT concept is obtained by demodulating the CPSK data signal. The detection and prediction can then be obtained from the data bits.

Figure 23 shows a CDM-PN multiplexer [11] and Figure 24 shows a TDM-PN multiplexer. These multiplexers are on the ground control facility. On the satellite no processing is done; there is a frequency translating repeater only.

The final system design in block diagram form is given in Figure 25. A large amount of equipment is necessary for this design and some may not be easy to obtain. The complexity of this design is such that the equipment needed takes on the complexity of a computer.

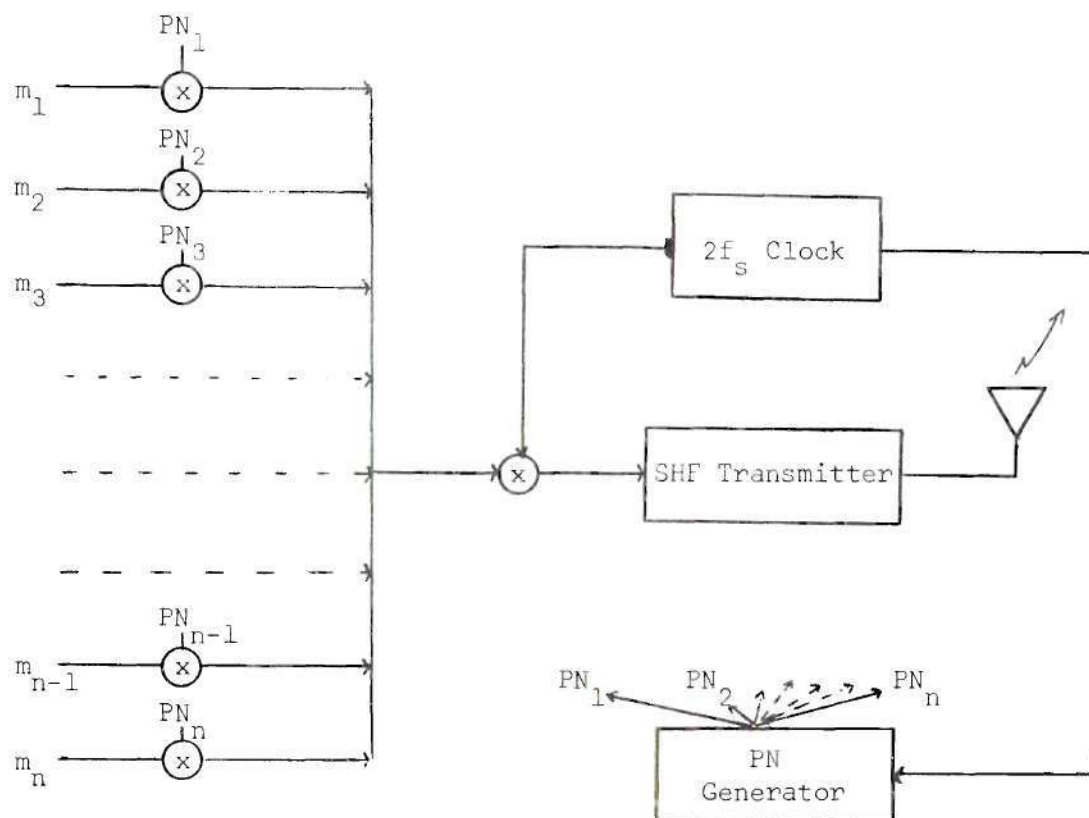


Figure 23. CDM-PN Ground Transmitter

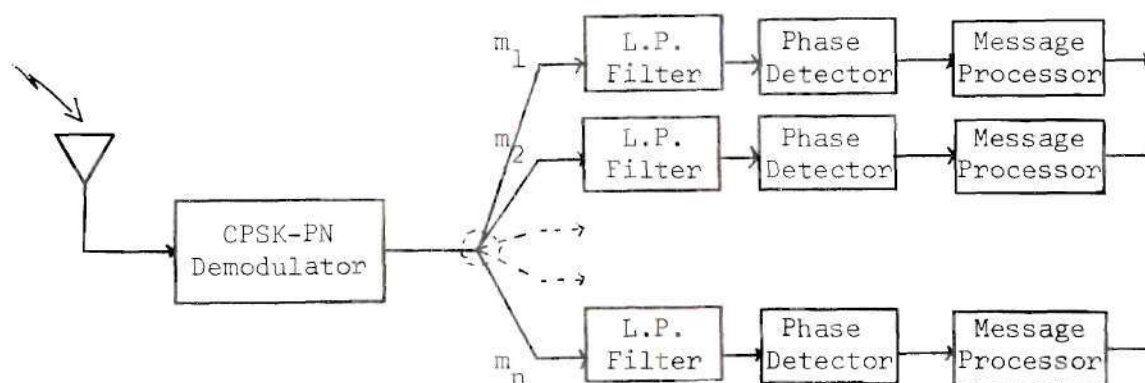


Figure 24. TDM-PN Ground Receiver

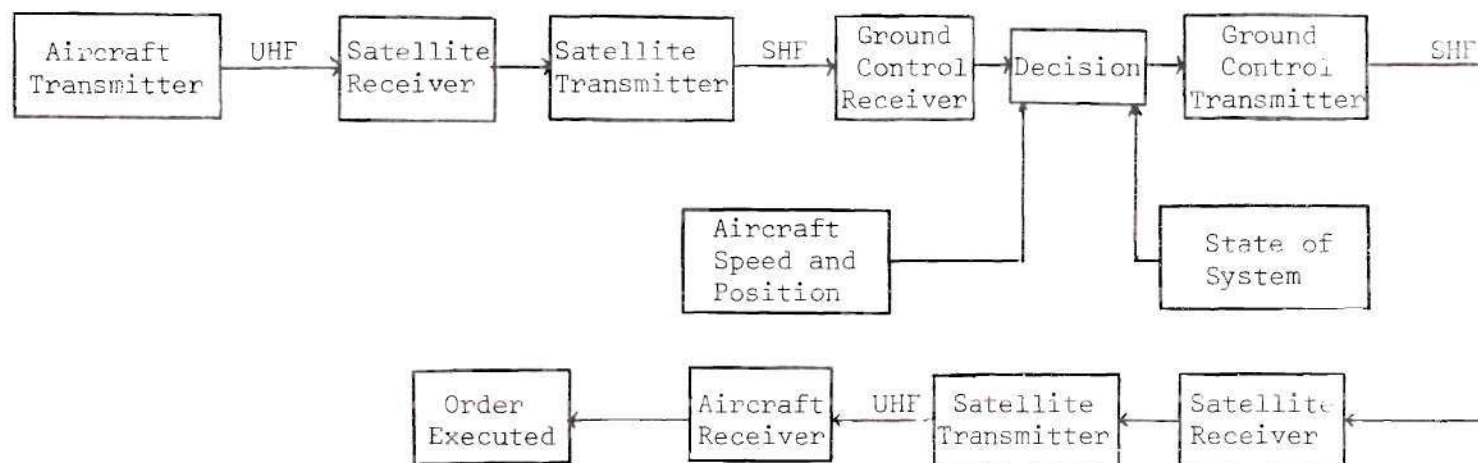


Figure 25. Block Diagram of Final System Design

CHAPTER IV

CONCLUSIONS

The use of satellites for the relay of aircraft-ground-aircraft communications has the obvious advantage of extensive line-of-sight service coverage which obviates the need for beyond-the-horizon propagation modes. In line-of-sight radio systems with terminals on the earth's surface, the reflections and scatterings from the surface of the earth provide a secondary path between antennas which is slightly longer than the direct path; this signal interferes with the direct signal.

Detection and prediction pose no problems theoretically. Probably the biggest problem is obtaining the probability density functions of a "good" system, "bad" system, "bad system going worse," "bad system getting better," and a "bad system staying as it is," etc. Once these probability densities are obtained then the problem becomes that of sending the data obtained from the system on the aircraft to the ground with the best possible efficiency and the least probability of error. The modulation and links suggested shows that this is fulfilled under the assumption made and with the data available. A lot of study and experimentation is being done in this area.

In the event that a system has been detected to be "bad," a decision whether to land the aircraft, keep flying, or any other order, is made by the ground controller or the aircraft commander. Precise

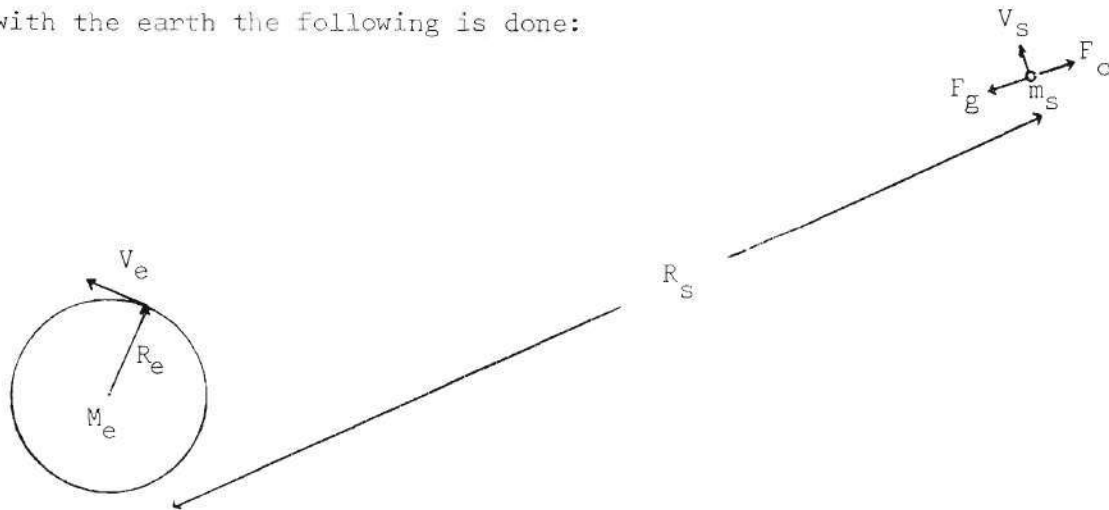
speed and position will help in the decision; thus SPOT can play an important role in the system design.

Airlines and owners have always been concerned with efficient and low cost systems which aid in preventing tragedies. With the advent of jumbo jets for commercial use and "flying monsters" like the C-5A transport for defense use, these become even more important. The loss of one of these huge aircraft can involve the loss of many lives and large amounts of money. Detection and/or prediction of a system failing on an aircraft can well be a first step towards preventing these losses. Another step might then be tracking and exact determination of the position and speed of the aircraft by phase measurement techniques.

APPENDIX I

SPOT

1. To determine at what altitude a satellite is synchronized with the earth the following is done:



Let F_g be the gravitational force

F_c be the centrifugal force

R_s be the distance from center of earth to satellite

R_e be the radius of the earth

M_e be the mass of the earth

m_s be the mass of the satellite

V_s be the linear speed of the satellite

$$F_g = \frac{G M_e m_s}{R_s^2} = F_c = \frac{m_s V_s^2}{R_s}$$

$$V_e = \frac{2\pi R_e}{T} = \frac{2\pi R_e}{24 \text{ hr}} \cdot \frac{1 \text{ hr}}{3600 \text{ sec}} = \frac{\pi R_e}{43200} \text{ m/sec}$$

but

$$V_s^2 = \frac{G M_e}{R_s} = \left[\frac{\pi}{43200} \right]^2 R_s^2 (\text{m/sec})^2$$

therefore

$$R_s^3 = G M_e \cdot \left[\frac{43200}{\pi} \right]^2 [\text{m/sec}]^2$$

but

$$G = 6.67(10^{-11}) \text{ nt m}^2/\text{kg}^2$$

and

$$M_e = 6.60(10^{24}) \text{ kg}$$

$$R_e = 6.70(10^7) \text{ m}$$

thus

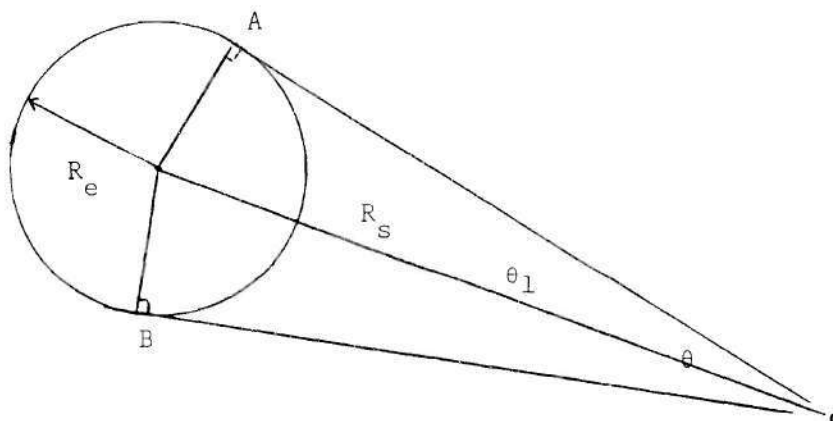
$$R_s^3 = \left\{ (6.67)(6.60)(4.32)^2(10^{21}) \right\} / (\pi)^2 = 81.80(10^{21}) \text{ m}^3$$

Hence

$$R_s = 26300 \text{ miles}$$

Thus the distance from the surface of the earth to a 24-hour satellite is about 22300 miles.

2. To determine the angle of elevation that the satellite covers:



where $\sin(\theta_1) = \frac{4000}{26300} = 0.152$, then $\theta_1 = \sin^{-1}(0.152) = 8.75^\circ$

but

$$\theta = 2\theta_1 = 2(8.75) = 17.50^\circ$$

and

$$\begin{aligned} \widehat{AB} &= (2\pi R_e \text{ miles}) \left(\frac{(90 - \theta_1)}{360^\circ} \right) \\ &= 2(2\pi 4000) \left(\frac{81.25}{360^\circ} \right) = 11320 \text{ miles} \end{aligned}$$

3. To determine the total number of satellites needed for worldwide coverage:

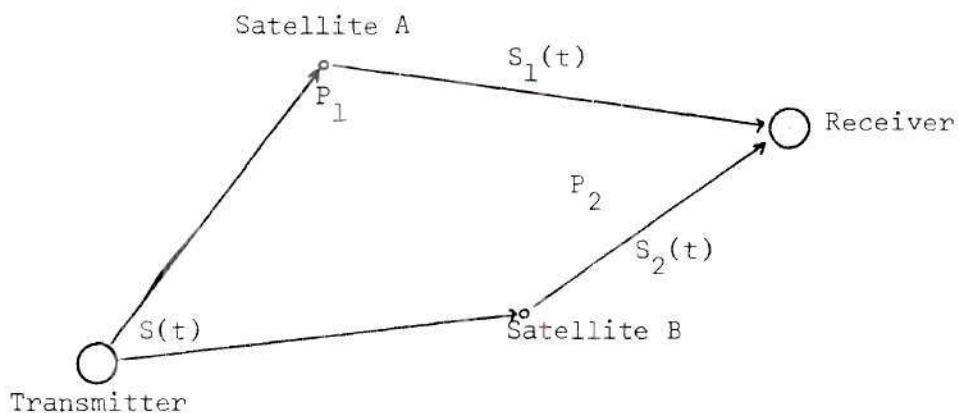
In order to obtain worldwide coverage, twice the circumference of the earth would have to be covered. This is because two satellites per phase measurement are needed. Then

Total distance to be covered, $D = 2(2\pi 4000) = 2(25200) = 50400$ miles

but each satellite covers 11320 miles (see 2), therefore

$$\text{Number of satellites, } N = \frac{50400}{11320} = 4.45 \approx \underline{5}$$

4. To determine how a travelling signal picks up a phase as it travels through space:



say $S(t) = A \cos(\omega_c t + \theta)$ and $P_1 > P_2$

and T_1 = time at which $S(t)$ got to the receiver along path P_1
(dist. D_1)

T_2 = time at which $S(t)$ got to the receiver along path P_2
(dist. D_2),

and

$T_1 = D_1/C$ where C is the speed of light (186000 mps)

$T_2 = D_2/C$

then

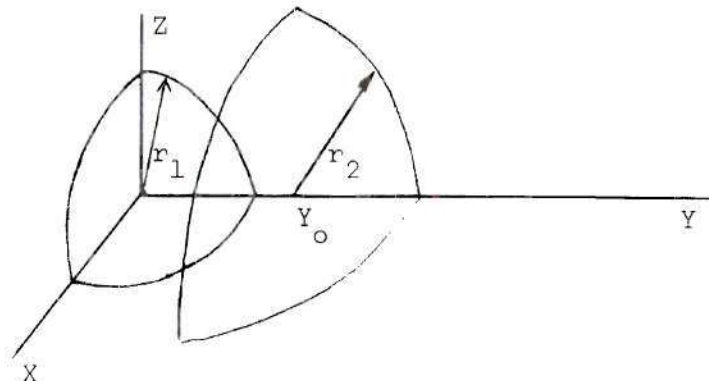
$$S_1(t) = A \cos(w_c(t+T_1) + \theta) \quad \text{and} \quad S_2(t) = A \cos(w_c(t+T_2) + \theta).$$

Comparing $S_1(t)$ and $S_2(t)$ with the transmitted message $S(t)$, it can be seen that the difference is

$$w_c(D_1/C) \quad \text{and} \quad w_c(D_2/C)$$

these being the phase introduced because of the distances involved.

5. To determine that intersection of two spheres gives a circle:



the equation of the spheres are

$$X^2 + Y^2 + Z^2 = r_1^2 \quad (13)$$

$$X^2 + (Y - Y_o)^2 + Z^2 = r_2^2 \quad (14)$$

or

$$X^2 + Y^2 + Z^2 - r_1^2 = 0$$

$$X^2 + (Y - Y_o)^2 + Z^2 - r_2^2 = 0$$

by subtracting,

$$Y^2 - (Y - Y_o)^2 - r_1^2 + r_2^2 = 0$$

then

$$Y^2 - Y^2 + 2YY_o - Y_o^2 = r_1^2 - r_2^2$$

therefore

$$Y = (r_1^2 - r_2^2 + Y_o^2) / 2Y_o = \text{constant} = A$$

substituting into (13) you get

$$X^2 + A^2 + Z^2 = r_1^2$$

Hence

$$X^2 + Z^2 = r_1^2 + A^2 = C^2 = \text{a constant} \quad (15)$$

Equation (15) becomes the equation of a circle on the $X-Z$ axis with radius C and origin at $(0,A,0)$.

APPENDIX II

1. These are the computer algorithms used for deciding the type of link to use for the design. The noise levels used are clearly shown in the algorithm. The satellite receiver noise power density, N_w , is 20 times as large as the ground receiver noise power density, N_o , for SHF-UHF links; for UHF-UHF links N_w is equal to N_o .

In this program the maximum normalized SNR is sought. The P that will give this normalized SNR will be used in the next program to solve for the SNR of each link. Here all possible cases are covered. There is more information than needed for this design.

```

C PERFORMANCE CHARACTERISTICS OF PN UHF-SHF LINK
C   FOR MASTERS THESIS
C PT=SUM OF ALL PI
C PI=POWER RECEIVED BY SATELLITE FROM ITH TRANSMITTER
C NW=SATELLITE RECEIVER NOISE POWER DENSITY
C NO=GROUND RECEIVER NOISE POWER DENSITY
C PR=SATELLITE REPEATER POWER RECEIVED BY GROUND STATION
C B=TOTAL RF BANDWIDTH
C JW=POWER IN SATELLITE DUE TO INTERFERENCE
C JO=POWER IN GROUND RECEIVER DUE TO INTERFERENCE
      DIMENSION SNRP(15,200)
      REAL SNRP,P,PM,A,B,RO,R
      INTEGER N,I,K,L,M,J
      1 FORMAT(1X,13H UHF-SHF LINK)
      4 FORMAT(1X,27H SATELLITE MULTIPATH POWER=,F5.1,35HPT
      8D MULTIPATH POWER=,F5.1,2HPR)
      21 FORMAT(1X,13H      PM = 0.0 )
      22 FORMAT(1X,39H RO      P = 100.      P = 10.0      P = 1.00,
      124H      P = 0.10      P = 0.01)
      23 FORMAT(1X,F5.2,2X,F8.6,4X,F8.6,4X,F8.6,4X,F8.6,4X,F8.6)
      24 FORMAT(1X,13H      PM = 0.2 )
      25 FORMAT(1X,F5.2,2X,F8.6,4X,F8.6,4X,F8.6,4X,F8.6,4X,F8.6)
      26 FORMAT(1X,13H      PM = 1.0 )
      27 FORMAT(1X,F5.2,2X,F8.6,4X,F8.6,4X,F8.6,4X,F8.6,4X,F8.6)
      37 FORMAT(1X,25H SHF-UHF AND UHF-UHF LINK)
      WRITE(6,1)
C P=PR/PT, A=JW/PT, B=JO/PR, RO=B*NW/PT, N=NW/NO, PM=PI/PT
      K=0
      L=0
      N=20
      35 A=1.0
      B=0.0
      31 I=0
      GO TO 2
      5 DO 3 M=1,200,2
      R=M
      RO=R/10.
      J=M
      SNRP(I,J)=(1+A+2*SQRT(P*N)*SQRT((1+A)*(1+B)-PM)
      1 + (P*N*(1+B)))/((((P*N)/RO)*((1+B)*(1+A+RO)
      2 -PM)))+(1+A+RO))

```

```

3 CONTINUE
  IF (I .EQ. 1) GO TO 6
  IF (I .EQ. 2) GO TO 7
  IF (I .EQ. 3) GO TO 8
  IF (I .EQ. 4) GO TO 9
  IF (I .EQ. 5) GO TO 10
  IF (I .EQ. 6) GO TO 11
  IF (I .EQ. 7) GO TO 12
  IF (I .EQ. 8) GO TO 13
  IF (I .EQ. 9) GO TO 14
  IF (I .EQ. 10) GO TO 15
  IF (I .EQ. 11) GO TO 16
  IF (I .EQ. 12) GO TO 17
  IF (I .EQ. 13) GO TO 18
  IF (I .EQ. 14) GO TO 19
  IF (I .EQ. 15) GO TO 20
2 CONTINUE
C UHF-SHF LINK
  I=1
  PM=0.0
  P=100.0
  WRITE(6,4) A,B
  GO TO 5
6 CONTINUE
C UHF-SHF LINK
  I=2
  PM=0.2
  GO TO 5
C
7 CONTINUE
C UHF-SHF LINK
  I=3
  PM=1.
  GO TO 5
8 CONTINUE
C UHF-SHF LINK
  I=4
  PM=0.0
  P=10.
  GO TO 5
9 CONTINUE
C UHF-SHF LINK
  I=5
  PM=0.2
  GO TO 5
10 CONTINUE
C UHF-SHF LINK

```



```
      I=6
      PM=1.
      GO TO 5
11  CONTINUE
C UHF-SHF LINK
      I=7
      PM=0.
      P=1.
      GO TO 5
12  CONTINUE
C UHF-SHF LINK
      I=8
      PM=0.2
      GO TO 5
13  CONTINUE
      I=9
      PM=1.
      GO TO 5
14  CONTINUE
C UHF-SHF LINK
      I=10
      P=0.1
      PM=0.
      GO TO 5
15  CONTINUE
C UHF-SHF LINK
      I=11
      PM=0.2
      GO TO 5
16  CONTINUE
C UHF-SHF LINK
      I=12
      PM=1.
      GO TO 5
17  CONTINUE
C UHF-SHF LINK
      I=13
      P=0.01
      PM=0.
      GO TO 5
18  CONTINUE
C UHF-SHF LINK
      I=14
      PM=0.2
      GO TO 5
19  CONTINUE
C UHF-SHF LINK
```

```

      I=15
      PM=1.
      GO TO 5
20  CONTINUE
      WRITE(6,21)
      WRITE(6,22)
      DO 28 M=1,200,2
      R=M
      RO=R/10.
      J=M
      WRITE(6,23) RO,SNRP(1,J),SNRP(4,J),SNRP(7,J),
1  SNRP(10,J),SNRP(13,J)
28  CONTINUE
      WRITE(6,24)
      DO 29 M=1,200,2
      R=M
      RO=R/10.
      J=M
      WRITE(6,25) RO,SNRP(2,J),SNRP(5,J),SNRP(8,J),
1  SNRP(11,J),SNRP(14,J)
29  CONTINUE
      WRITE(6,26)
      DO 30 M=1,200,2
      R=M
      RO=R/10.
      J=M
      WRITE(6,27) RO,SNRP(3,J),SNRP(6,J),SNRP(9,J),
1  SNRP(12,J),SNRP(15,J)
30  CONTINUE
      IF (K .EQ. 3) GO TO 34
      IF (K .EQ. 2) GO TO 33
      IF (K .EQ. 1) GO TO 32
      K=1
      A=1.
      B=1.
      GO TO 31
32  CONTINUE
      K=2
      A=0.
      B=0.
      GO TO 31
33  CONTINUE
      K=3
      A=0.
      B=1.
      GO TO 31
34  CONTINUE

```

```
IF (L .EQ. 1) GO TO 36  
WRITE(6,37)  
N=1  
K=4  
L=1  
GO TO 35  
36 CONTINUE  
STOP  
END
```

Based on the ρ that gave the maximum SNR on the previous program, the SNR is found for each case, i.e. VHF-SHF, SHF-VHF, UHF-UHF, all for different interference levels. Again, there is more information than needed in this program. The data of this program is based on the previous program.

```

C OPTIMUM DETECTOR SIGNAL TO NOISE RATIO FOR UHF-SHF LINKS
C PT=SUM OF ALL PI
C PI=POWER RECEIVED BY SATELLITE FROM I-TH TRANSMITTER
C NW=SATELLITE RECEIVER NOISE POWER DENSITY
C NO=GROUND RECEIVER NOISE POWER DENSITY
C PR=SATELLITE REPEATER POWER RECEIVED BY GRUND STATION
C PR=SATELLITE REPEATER POWER RECEIVED BY GROUND STATION
C B=TOTAL RF BANDWIDTH
C JW=POWER IN SATELLITE DUE TO INTERFERENCE
C JO=POWER IN GROUND RECEIVER DUE TO INTERFERENCE
C PC=CLUTTER POWER LOST
C P=PR/PT, A=JW/PT, B=JO/PR, RO=B*NW/PT, N=NW/NO, PM=PI/PT,
C   PN=PC/PT
   REAL P,A,B,RO,PM,PN,SNRON1,SNRON2,N
   INTEGER I
   I=1
4  CONTINUE
   READ(5,1) A,B,N,P,PM,PN,RO
1  FORMAT(      )
   WRITE(6,2) A,B,N,P,PM,PN,RO
2  FORMAT(1X,4H A =,F4.1,7X,4H B =,F4.1,7X,4H N =,F4.1,
17X,4H P =,F6.2,7X,5H PM =,F4.1,7X,5H PN =,F4.1,
27X,5H RO =,F8.3)
C SNRON1 = SIGNAL TO NOISE RATIO OPTIMIZED AND NORMALIZED
C   WITH PR AS VA.
C SNRON2 = SIGNAL TO NOISE RATIO OPTIMIZED AND NORMALIZED
C   WITH PI AS VA.
   SNRON1 = (N*PM)/(((N*P)/RO)*(A+RO+PN)
1 + (1+(B*P*N)/RO)*(1+A+RO))
   SNRON2 = (N*P)/(((N*P)/RO)*(A+RO+PN)
1 + (1+(B*P*N)/RO)*(1+A+RO))
   WRITE(6,3) SNRON1,SNRON2
3  FORMAT(10X,6H SNR =,F8.4,10H (PR*T/NW),10X,6H SNR =,
1F8.4,10H (PI*T/NW))
   IF (I .EQ. 241) GO TO 5
   I=I+1
   GO TO 4
5  CONTINUE
   STOP
   END

1.,0.,20.,100.,0.,0.,24.
1.,0.,20.,10.,0.,0.,20.
1.,0.,20.,1.,0.,0.,6.3

```

```

1.0.20.0.1.0.0.2.1
1.0.20.0.01.0.0.0.7
1.0.20.100.0.2.0.23.
1.0.20.10.0.2.0.18.9
1.0.20.1.0.2.0.6.1
1.0.20.0.1.0.2.0.1.9
1.0.20.0.01.0.2.0.0.7
1.0.20.100.1.0.22.
1.0.20.10.1.0.14.1
1.0.20.1.1.0.4.5
1.0.20.0.1.1.0.1.5
1.0.20.0.01.1.0.0.5
1.1.20.100.0.0.21.
1.1.20.10.0.0.22.
1.1.20.1.0.0.8.9
1.1.20.0.1.0.0.2.9
1.1.20.0.01.0.0.0.9
1.1.20.100.0.2.0.26.
1.1.20.10.0.2.0.24.
1.1.20.1.0.2.0.8.7
1.1.20.0.1.0.2.0.2.7
1.1.20.0.01.0.2.0.0.9
1.1.20.100.1.0.22.
1.1.20.10.1.0.21.
1.1.20.1.1.0.7.7
1.1.20.0.1.1.0.2.5
1.1.20.0.01.1.0.0.7
0.0.1.100.0.0.9.9
0.0.20.10.0.0.14.1
0.0.20.1.0.0.4.5
0.0.20.0.1.0.0.1.5
0.0.20.0.01.0.0.0.5
0.0.20.100.0.2.0.21.
0.0.20.10.0.2.0.12.7
0.0.20.1.0.2.0.4.1
0.0.20.0.1.0.2.0.1.3
0.0.20.0.01.0.2.0.0.5
0.0.20.100.1.0.0.06
0.0.20.10.1.0.0.05
0.0.20.1.1.0.0.04
0.0.20.0.1.1.0.0.03
0.0.20.0.01.1.0.0.02
0.1.20.100.0.0.23.
0.1.20.10.0.0.20.
0.1.20.1.0.0.6.3
0.1.20.0.1.0.0.2.1
0.1.20.0.01.0.0.0.7

```

0.,1.,20.,100.,0.2,0.,21.
 0.,1.,20.,10.,0.2,0.,18.9
 0.,1.,20.,1.,0.2,0.,6.1
 0.,1.,20.,0.1,0.2,0.,1.9
 0.,1.,20.,0.01,0.2,0.,0.7
 0.,1.,20.,100.,1.,0.,21.
 0.,1.,20.,10.,1.,0.,14.1
 0.,1.,20.,1.,1.,0.,4.5
 0.,1.,20.,0.1,1.,0.,1.5
 0.,1.,20.,0.01,1.,0.,0.5
 1.,0.,1.,100.,1.,0.,14.1
 1.,0.,1.,10.,0.,0.,4.5
 1.,0.,1.,1.,0.,0.,1.5
 1.,0.,1.,0.1,0.,0.,0.5
 1.,0.,1.,0.01,0.,0.,0.08
 1.,0.,1.,100.,0.2,0.,13.5
 1.,0.,1.,10.,0.2,0.,4.3
 1.,0.,1.,1.,0.2,0.,1.3
 1.,0.,1.,0.1,0.2,0.,0.5
 1.,0.,1.,0.01,0.2,0.,0.07
 1.,0.,1.,100.,1.,0.,9.9
 1.,0.,1.,10.,1.,0.,3.1
 1.,0.,1.,1.,1.,0.,1.1
 1.,0.,1.,0.1,1.,0.,0.3
 1.,0.,1.,0.01,1.,0.,0.1
 1.,1.,1.,100.,0.,0.,19.9
 1.,1.,1.,10.,0.,0.,6.3
 1.,1.,1.,100.,1.,0.,17.3
 1.,1.,1.,10.,1.,0.,5.5
 1.,1.,1.,1.,1.,0.,1.7
 1.,1.,1.,0.1,1.,0.,0.5
 1.,1.,1.,0.01,1.,0.,0.08
 0.,0.,20.,100.,0.,0.,21.
 0.,0.,1.,10.,0.,0.,3.1
 0.,0.,1.,1.,0.,0.,1.1
 0.,0.,1.,0.1,0.,0.,0.3
 0.,0.,1.,0.01,0.,0.,0.1
 0.,0.,1.,100.,0.2,0.,8.9
 0.,0.,1.,10.,0.2,0.,2.9
 0.,0.,1.,1.,0.2,0.,0.9
 0.,0.,1.,0.1,0.2,0.,0.3
 0.,0.,1.,0.01,0.2,0.,0.07
 0.,0.,1.,100.,1.,0.,0.05
 0.,0.,1.,10.,1.,0.,0.04
 0.,0.,1.,1.,1.,0.,0.03
 0.,0.,1.,0.1,1.,0.,0.02
 0.,0.,1.,0.01,1.,0.,0.01


```

0.1.1. 100.0.0.0.14.1
0.1.1. 10.0.0.0.4.5
0.1.1. 1.0.0.0.1.5
0.1.1. 0.1.0.0.0.5
0.1.1. 0.01.0.0.0.0.9
0.1.1. 100.0.2.0.13.5
0.1.1. 10.0.2.0.4.3
0.1.1. 1.0.2.0.1.3
0.1.1. 0.1.0.2.0.0.5
0.1.1. 0.01.0.2.0.0.0.9
0.1.1. 100.1.0.10.1
0.1.1. 10.1.0.3.1
0.1.1. 1.1.0.1.1
0.1.1. 0.1.1.0.0.3
0.1.1. 0.01.1.0.0.1
1.0.20.100.0.1.24.
1.0.20.10.0.1.20.
1.0.20.1.0.1.6.3
1.0.20.0.1.0.1.2.1
1.0.20.0.01.0.1.0.7
1.0.20.100.0.2.1.23.
1.0.20.10.0.2.1.18.9
1.0.20.1.0.2.1.6.1
1.0.20.0.1.0.2.1.1.9
1.0.20.0.01.0.2.1.0.7
1.0.20.100.1.1.22.
1.0.20.10.1.1.14.1
1.0.20.1.1.1.4.5
1.0.20.0.1.1.1.5
1.0.20.0.01.1.1.0.5
1.1.20.100.0.1.21.
1.1.20.10.0.1.22.
1.1.20.1.0.1.8.9
1.1.20.0.1.0.1.2.9
1.1.20.0.01.0.1.0.9
1.1.20.100.0.2.1.26.
1.1.20.10.0.2.1.24.
1.1.20.1.0.2.1.8.7
1.1.20.0.1.0.2.1.2.7
1.1.20.0.01.0.2.1.0.9
1.1.20.100.1.1.22.
1.1.20.10.1.1.21.
1.1.20.1.1.1.7.7
1.1.20.0.1.1.1.1.5
1.1.20.0.01.1.1.0.7
0.0.20.100.0.1.21.
0.0.20.10.0.1.14.1

```

0.,0.,20.,1.,0.,1.,4.5
 0.,0.,20.,0.1,0.,1.,1.5
 0.,0.,20.,0.01,0.,1.,0.5
 0.,0.,20.,100.,0.2,1.,21.
 0.,0.,20.,10.,0.2,1.,12.7
 0.,0.,20.,1.,0.2,1.,4.1
 0.,0.,20.,0.1,0.2,1.,1.3
 0.,0.,20.,0.01,0.2,1.,0.5
 0.,0.,20.,100.,1.,1.,0.06
 0.,0.,20.,10.,1.,1.,0.05
 0.,0.,20.,1.,1.,1.,0.04
 0.,0.,20.,0.1,1.,1.,0.03
 0.,0.,20.,0.01,1.,1.,0.02
 0.,1.,20.,100.,0.,1.,23.
 0.,1.,20.,10.,0.,1.,20.
 0.,1.,20.,1.,0.,1.,6.3
 0.,1.,20.,0.1,0.,1.,2.1
 0.,1.,20.,0.01,0.,1.,0.7
 0.,1.,20.,100.,0.2,1.,21.
 0.,1.,20.,10.,0.2,1.,18.9
 0.,1.,20.,1.,0.2,1.,6.1
 0.,1.,20.,0.1,0.2,1.,1.9
 0.,1.,20.,0.01,0.2,1.,0.7
 0.,1.,20.,100.,1.,1.,21.
 0.,1.,20.,10.,1.,1.,14.1
 0.,1.,20.,1.,1.,1.,4.5
 0.,1.,20.,0.1,1.,1.,1.5
 0.,1.,20.,0.01,1.,1.,0.5
 1.,0.,1.,100.,1.,1.,14.1
 1.,0.,1.,10.,0.,1.,4.5
 1.,0.,1.,1.,0.,1.,1.5
 1.,0.,1.,0.1,0.,1.,0.5
 1.,0.,1.,0.01,0.,1.,0.08
 1.,0.,1.,100.,0.2,1.,13.5
 1.,0.,1.,10.,0.2,1.,4.3
 1.,0.,1.,1.,0.2,1.,1.3
 1.,0.,1.,0.1,0.2,1.,0.5
 1.,0.,1.,0.01,0.2,1.,0.07
 1.,0.,1.,100.,1.,1.,9.9
 1.,0.,1.,10.,1.,1.,3.1
 1.,0.,1.,1.,1.,1.,1.1
 1.,0.,1.,0.1,1.,1.,0.3
 1.,0.,1.,0.01,1.,1.,0.1
 1.,1.,1.,100.,0.,1.,19.9
 1.,1.,1.,10.,0.,1.,6.3
 1.,1.,1.,1.,0.,1.,2.1
 1.,1.,1.,0.1,0.,1.,0.7

```

1.1.1.1. 20.0120.1.0.3
1.1.1.1. 100.20.21.19.5
1.1.1.1. 10.20.21.6.1
1.1.1.1. 1.20.21.2.1
1.1.1.1. 20.120.21.0.7
1.1.1.1. 20.0120.21.0.3
1.1.1.1. 100.1.1.17.3
1.1.1.1. 10.21.1.5.5
1.1.1.1. 1.21.1.1.7
1.1.1.1. 20.121.1.0.5
1.1.1.1. 20.0121.1.0.08
0.20.1. 100.20.1.9.9
0.20.1. 10.20.1.3.1
0.20.1. 1.20.1.1.1
0.20.1. 20.120.1.0.3
0.20.1. 20.0120.1.8.9
0.20.1. 10.20.21.2.9
0.20.1. 1.20.21.0.9
0.20.1. 20.120.21.0.3
0.20.1. 20.0120.21.0.07
0.20.1. 100.1.1.0.05
0.20.1. 10.1.1.0.04
0.20.1. 1.1.1.0.03
0.20.1. 20.121.1.0.02
0.20.1. 20.01. 1.1.0.01
0.1.1. 100.20.1.14.1
0.1.1. 10.20.1.4.5
0.1.1. 1.20.1.1.5
0.1.1. 20.120.1.0.5
0.1.1. 20.0120.1.0.09
0.1.1. 100.20.21.13.5
0.1.1. 10.20.21.4.3
0.1.1. 1.20.21.1.3
0.1.1. 20.120.21.0.5
0.1.1. 20.0120.21.0.09
0.1.1. 100.1.1.10.1
0.1.1. 10.1.1.3.1
0.1.1. 1.1.1.1.1
0.1.1. 20.121.1.0.3
0.1.1. 20.0121.1.0.1

```

SHF-UHF link is studied here. The ERP of the satellite, the power transmitted by the aircraft, the bandwidth and the power received by the satellite are calculated. The value of $a = 1$ and $b = 0$ in this case. There is more information here than needed.

```

C OTHER PERFORMANCE PARAMETERS FOR MASTERS THESIS
C PT=SUM OF ALL PI
C PI=POWER RECEIVED BY SATELLITE FROM ITH TRANSMITTER
C NW=SATELLITE RECEIVER NOISE POWER DENSITY
C NO=GROUND RECEIVER NOISE POWER DENSITY
C PRG=SATELLITE REPEATER POWER RECEIVED BY GROUND STATION
C BW=TOTAL RF BANDWIDTH
C JW=POWER IN SATELLITE DUE TO INTERFERENCE
C JO=POWER IN GROUND RECEIVER DUE TO INTERFERENCE
C ERPSG=EFFECTIVE RADIATED POWER FROM SATELLITE TO GROUND
C PTA=POWER TRANSMITTED FROM AIRCRAFT
C R=DISTANCE FROM SATELLITE TO GROUND STATION
C RA=DISTANCE FROM SATELLITE TO AIRCRAFT
C F=TRANSMITTING FREQUENCY IN MEGACYCLES
C FN=FREQUENCY IN MEGACYCLES
C PE=PROBABILITY OF ERROR (NOT NEEDED FOR THESE CALCULATIONS)
C LO=ATMOSPHERIC LOSSES (PATH LOSSES) AT UHF FREQUENCY
C LON=ATMOSPHERIC LOSSES (PATH LOSSES) AT SHF FREQUENCY
C P=PR/PT, A=JW/PT, B=JO/PR, RO=B*NW/PT, N=NW/NO, PM=PI/PT
  REAL N,PM,NW,A,B,PI1,PI,PT1,PT,PTA,PRG1,PRG,
  1X,NO,PE,SNR,H,F,R,GT,GR,LO,LOA,RA,ERPSG,BW,L
  INTEGER I
  H=2400.
  GT=0.
  GR=0.
  F=400.
  FN=4000.
  R=22300.
  RA=26300.
  PE=10.**(-3)
  SNR=4.82
  NW=1.124*10.**(-20)
  LO=37.+20.*ALOG10(F)+20.*ALOG10(R)
  LOA=37.+20.*ALOG10(F)+20.*ALOG10(RA)
  LON=37.+20.*ALOG10(FN)+20.*ALOG10(RA)
  WRITE(6,40) LU,LOA
40  FORMAT(10X,1PE10.4,10X,1PE10.4)
  WRITE(6,41) LON
41  FORMAT(5X,F8.2)
C UHF-SHF LINKS ONLY
C UHF-SHF LINK (UP LINK)

```



```

N=20.
PM=0.2
NO=NW/N
A=1.
B=0.
WRITE(6,2)
2 FORMAT(1X,12HPI1 IN WATTS,3X,9HPI IN DBW,3X,
112HPT1 IN WATTS,3X,9HPT IN DBW,3X,10HPTA IN DBW,
23X,13HPRG1 IN WATTS,3X,10HPRG IN DBW,3X,12HERPSG IN DBW,
33X,8HBW IN HZ,4X,2HPM)
GO TO 3
4 PI1=((SNR*NW*H)/X)
PI=10.*ALOG10(PI1)
PT1=5.*PI1
PT=10.*ALOG10(PT1)
PTA=PI+GT+GR-LOA
PRG1=L*PT1
PRG=10.*ALOG10(PRG1)
ERPSG=PRG+LO-GT-GR
BW=SQRT((PRG1/NW)*(PT1/NO)*((1+A)*(1+B)-PM))
WRITE(6,30) PI1,PI,PT1,PT,PTA,PRG1,PRG,ERPSG,BW,PM
30 FORMAT(3X,1PE8.2,5X,1PE8.2,6X,1PE8.2,5X,1PE8.2,
15X,1PE8.2,7X,1PE8.2,6X,1PE8.2,6X,1PE8.2,5X,1PE8.2,
32X,0PF7.4)
IF (I .EQ. 1) GO TO 5
IF (I .EQ. 2) GO TO 6
IF (I .EQ. 3) GO TO 7
IF (I .EQ. 4) GO TO 8
IF (I .EQ. 5) GO TO 9
IF (I .EQ. 6) GO TO 10
3 CONTINUE
I=1
L=100.
X=0.9095
GO TO 4
5 CONTINUE
I=I+1
L=1.
X=0.5771
GO TO 4
6 CONTINUE
I=I+1
L=0.01
X=0.0576
GO TO 4
7 CONTINUE
I=I+1

```

```
L=100.  
PM=1.  
X=0.9457  
GO TO 4  
8 CONTINUE  
I=I+1  
L=1.  
X=0.6463  
GO TO 4  
9 CONTINUE  
I=I+1  
L=0.01  
X=0.0645  
GO TO 4  
10 CONTINUE  
STOP  
END
```


UHF-UHF link is studied here. $a = 1$ and $b = 0$ in this case. The bandwidth, satellite ERP, and the power received by the satellite are calculated. There is more information here than needed.

```

C OTHER PERFORMANCE PARAMETERS FOR MASTERS THESIS
C PT=SUM OF ALL PI
C PI=POWER RECEIVED BY SATELLITE FROM ITH TRANSMITTER
C NW=SATELLITE RECEIVER NOISE POWER DENSITY
C NO=GROUND RECEIVER NOISE POWER DENSITY
C PRG=SATELLITE REPEATER POWER RECEIVED BY GROUND STATION
C BW=TOTAL RF BANDWIDTH
C JW=POWER IN SATELLITE DUE TO INTERFERENCE
C JO=POWER IN GROUND RECEIVER DUE TO INTERFERENCE
C ERPSG=EFFECTIVE RADIATED POWER FROM SATELLITE TO GROUND
C PTA=POWER TRANSMITTED FROM AIRCRAFT
C R=DISTANCE FROM SATELLITE TO GROUND STATION
C RA=DISTANCE FROM SATELLITE TO AIRCRAFT
C F=TRANSMITTING FREQUENCY IN MEGACYCLES
C PE=PROBABILITY OF ERROR (NOT NEEDED FOR THESE CALCULATIONS)
C LO=ATMOSPHERIC LOSSES (PATH LOSSES) AT UHF FREQUENCY
C P=PR/PT, A=JW/PT, B=JO/PR, RO=B*NW/PT, N=NW/NO, PM=PI/PT
  REAL N,PM,NW,A,B,PI1,PI,PT1,PT,PTA,PRG1,PRG,
  1X,NO,PE,SNR,H,F,R,GT,GR,LU,LOA,RA,ERPSG,BW,L
  INTEGER I
  H=2400.
  GT=0.
  GR=0.
  F=400.
  R=22300.
  RA=26300.
  PE=10.**(-3)
  SNR=4.82
  NO=1.124*10.**(-20)
  LO=37.+20.*ALOG10(F)+20.*ALOG10(R)
  LOA=37.+20.*ALOG10(F)+20.*ALOG10(RA)
  WRITE(6,40) LU,LOA
  40 FORMAT(10X,1PE10.4,10X,1PE10.4)
C UHF=UHF LINK ONLY
  N=1.
  PM=0.2
  NW=N*NO
  A=1.
  B=0.
  WRITE(6,2)
  2 FORMAT(1X,12HP11 IN WATTS,3X,9HP1 IN DBW,3X,

```

```

112HPT1 IN WATTS,3X,9HPT IN DBW,3X,10HPTA IN DBW,
23X,13HPRG1 IN WATTS,3X,10HPRG IN DBW,3X,12HERPSG IN DBW,
33X,8HBW IN HZ,4X,2HPM)
GO TO 3
4 PI1=((SNR*NW*H)/X)
PI=10.*ALOG10(PI1)
PT1=5.*PI1
PT=10.*ALOG10(PT1)
PTA=PI+GT+GR-LOA
PRG1=L*PT1
PRG=10.*ALOG10(PRG1)
ERPSG=PRG+LO-GT-GR
BW=SQRT((PRG1/NW)*(PT1/NO)*((1+A)*(1+B)-PM))
WRITE(6,30) PI1,PI,PT1,PT,PTA,PRG1,PRG,ERPSG,BW,PM
30 FORMAT(3X,1PE8.2,5X,1PE8.2,6X,1PE8.2,5X,1PE8.2,
15X,1PE8.2,7X,1PE8.2,6X,1PE8.2,6X,1PE8.2,5X,1PE8.2,
32X,0PF7.4)
IF (I .EQ. 1) GO TO 5
IF (I .EQ. 2) GO TO 6
IF (I .EQ. 3) GO TO 7
IF (I .EQ. 4) GO TO 8
IF (I .EQ. 5) GO TO 9
IF (I .EQ. 6) GO TO 10
3 CONTINUE
I=1
L=100.
X=0.7674
GO TO 4
5 CONTINUE
I=I+1
L=1.
X=0.1713
GO TO 4
6 CONTINUE
I=I+1
L=0.01
X=0.0042
GO TO 4
7 CONTINUE
I=I+1
L=100.
PM=1.
X=0.8197
GO TO 4
8 CONTINUE
I=I+1
L=1.

```

```
      X=0.1976  
      GO TO 4  
9     CONTINUE  
      I=I+1  
      L=0.01  
      X=0.0045  
      GO TO 4  
10    CONTINUE  
      STOP  
      END
```

Here we want to find the ERP, power transmitted by the aircraft, the bandwidth, the power received by the satellite. The link covered in this program is UHF-SHF. Again, there is more information than needed in this program. Here $a = 0$, and $b = 0$.

```

C OTHER PERFORMANCE PARAMETERS FOR MASTERS THESIS
C PT=SUM OF ALL PI
C PI=POWER RECEIVED BY SATELLITE FROM ITH TRANSMITTER
C NW=SATELLITE RECEIVER NOISE POWER DENSITY
C NO=GROUND RECEIVER NOISE POWER DENSITY
C PRG=SATELLITE REPEATER POWER RECEIVED BY GROUND STATION
C BW=TOTAL RF BANDWIDTH
C JW=POWER IN SATELLITE DUE TO INTERFERENCE
C JO=POWER IN GROUND RECEIVER DUE TO INTERFERENCE
C ERPSG=EFFECTIVE RADIATED POWER FROM SATELLITE TO GROUND
C PTA=POWER TRANSMITTED FROM AIRCRAFT
C R=DISTANCE FROM SATELLITE TO GROUND STATION
C RA=DISTANCE FROM SATELLITE TO AIRCRAFT
C F=TRANSMITTING FREQUENCY IN MEGACYCLES
C PE=PROBABILITY OF ERROR (NOT NEEDED FOR THESE CALCULATIONS)
C LO=ATMOSPHERIC LOSSES (PATH LOSSES) AT UHF FREQUENCY
C P=PR/PT, A=JW/PT, B=JO/PR, RO=B*NW/PT, N=NW/NO, PM=PI/PT
  REAL N,PM,NW,A,B,PI1,PI,PT1,PT,PTA,PRG1,PRG,
  1X,NO,PE,SNR,H,F,R,GT,GR,LO,LOA,RA,ERPSG,BW,L
  INTEGER I
  H=2400.
  GT=0.
  GR=0.
  F=400.
  R=22300.
  RA=26300.
  PE=10.**(-3)
  SNR=4.82
  NW=1.124*10.**(-20)
  LO=37.+20.*ALOG10(F)+20.*ALOG10(R)
  LOA=37.+20.*ALOG10(F)+20.*ALOG10(RA)
  WRITE(6,40) LU,LOA
  40 FORMAT(10X,1PE10.4,10X,1PE10.4)
C UHF=SHF LINKS ONLY
C UHF=SHF LINK (UP LINK)
  N=20.
  PM=0.2
  NO=NW/N
  A=0.
  B=0.
  WRITE(6,2)

```

```

2 FORMAT(1X,12HP11 IN WATTS,3X,9HPI IN DBW,3X,
112HPT1 IN WATTS,3X,9HPT IN DBW,3X,10HPTA IN DBW,
23X,13HPRG1 IN WATTS,3X,10HPRG IN DBW,3X,12HERPSG IN DBW,
33X,8HBW IN HZ,4X,2HPM)
GO TO 3
4 PI1=((SNR*NW*H)/X)
PI=10.*ALOG10(PI1)
PT1=5.*PI1
PT=10.*ALOG10(PT1)
PTA=PI+GT+GR-LOA
PRG1=L*PT1
PRG=10.*ALOG10(PRG1)
ERPSG=PRG+LO-GT-GR
BW=SQRT((PRG1/NW)*(PT1/ND)*((1+A)*(1+B)=PM))
WRITE(6,30) PI1,PI,PT1,PT,PTA,PRG1,PRG,ERPSG,BW,PM
30 FORMAT(3X,1PE8.2,5X,1PE8.2,6X,1PE8.2,5X,1PE8.2,
15X,1PE8.2,7X,1PE8.2,6X,1PE8.2,6X,1PE8.2,5X,1PE8.2,
32X,0PF7.4)
IF (I .EQ. 1) GO TO 5
IF (I .EQ. 2) GO TO 6
IF (I .EQ. 3) GO TO 7
IF (I .EQ. 4) GO TO 8
IF (I .EQ. 5) GO TO 9
IF (I .EQ. 6) GO TO 10
3 CONTINUE
I=1
L=100.
X=0.9446
GO TO 4
5 CONTINUE
I=I+1
L=1.
X=0.6672
GO TO 4
6 CONTINUE
I=I+1
L=0.01
X=0.0952
GO TO 4
7 CONTINUE
I=I+1
L=100.
PM=1.
X=0.9995
GO TO 4
8 CONTINUE
I=I+1

```



```
L=1.  
X=0.9506  
GO TO 4  
9 CONTINUE  
I=I+1  
L=0.01  
X=0.1639  
GO TO 4  
10 CONTINUE  
STOP  
END
```

In this program the ERP, power transmitted by the aircraft, the bandwidth, and the power received by the satellite are calculated. The link is UHF-UHF with $a = b = 0$. There is also more information than needed.

```

C OTHER PERFORMANCE PARAMETERS FOR MASTERS THESIS
C PT=SUM OF ALL PI
C PI=POWER RECEIVED BY SATELLITE FROM ITH TRANSMITTER
C NW=SATELLITE RECEIVER NOISE POWER DENSITY
C NO=GROUND RECEIVER NOISE POWER DENSITY
C PRG=SATELLITE REPLATER POWER RECEIVED BY GROUND STATION
C BW=TOTAL RF BANDWIDTH
C JW=POWER IN SATELLITE DUE TO INTERFERENCE
C JO=POWER IN GROUND RECEIVER DUE TO INTERFERENCE
C ERPSG=EFFECTIVE RADIATED POWER FROM SATELLITE TO GROUND
C PTA=POWER TRANSMITTED FROM AIRCRAFT
C R=DISTANCE FROM SATELLITE TO GROUND STATION
C RA=DISTANCE FROM SATELLITE TO AIRCRAFT
C F=TRANSMITTING FREQUENCY IN MEGACYCLES
C PE=PROBABILITY OF ERROR (NOT NEEDED FOR THESE CALCULATIONS)
C LO=ATMOSPHERIC LOSSES (PATH LOSSES) AT UHF FREQUENCY
C P=PR/PT, A=JW/PT, B=JO/PR, RO=B*NW/PT, N=NW/NO, PM=PI/PT
  REAL N,PM,NW,A,B,PI1,PI,PT1,PT,PTA,PRG1,PRG,
  1X,NO,PE,SNR,H,F,R,GT,GR,LO,LQA,RA,ERPSG,BW,L
  INTEGER I
  H=2400.
  GT=0.
  GR=0.
  F=400.
  R=22300.
  RA=26300.
  PE=10.**(-3)
  SNR=4.82
  NO=1.124*10.**(-20)
  LO=37.+20.*ALOG10(F)+20.*ALOG10(R)
  LQA=37.+20.*ALOG10(F)+20.*ALOG10(RA)
  WRITE(6,40) LO,LQA
40 FORMAT(10X,1PE10.4,10X,1PE10.4)
C UHF=UHF LINK ONLY
  N=1.
  PM=0.2
  NW=N*NO
  A=0.
  B=0.
  WRITE(6,2)
2 FORMAT(1X,12HP11 IN WATTS,3X,9HP1 IN DBW,3X,

```

```

112HPT1 IN WATTS,3X,9HPT IN DBW,3X,10HPTA IN DBW,
23X,13HPRG1 IN WATTS,3X,10HPRG IN DBW,3X,12HERPSG IN DBW,
33X,8HBW IN HZ,4X,2HPM)
  GO TO 3
4  PI1=((SNR*NW*H)/X)
   PI=10.*ALOG10(PI1)
   PT1=5.*PI1
   PT=10.*ALOG10(PT1)
   PTA=PI+GT+GR=LOA
   PRG1=L*PT1
   PRG=10.*ALOG10(PRG1)
   ERPSG=PRG+LO=GT+GR
   BW=SQRT((PRG1/NW)*(PT1/NO)*((1+A)*(1+B)=PM))
   WRITE(6,30) PI1,PI,PT1,PT,PTA,PRG1,PRG,ERPSG,BW,PM
30  FORMAT(3X,1PE8.2,5X,1PE8.2,6X,1PE8.2,5X,1PE8.2,
15X,1PE8.2,7X,1PE8.2,6X,1PE8.2,6X,1PE8.2,5X,1PE8.2,
32X,0PF7.4)
   IF (I .EQ. 1) GO TO 5
   IF (I .EQ. 2) GO TO 6
   IF (I .EQ. 3) GO TO 7
   IF (I .EQ. 4) GO TO 8
   IF (I .EQ. 5) GO TO 9
   IF (I .EQ. 6) GO TO 10
3  CONTINUE
   I=1
   L=100.
   X=0.9099
   GO TO 4
5  CONTINUE
   I=I+1
   L=1.
   X=0.3448
   GO TO 4
6  CONTINUE
   I=I+1
   L=0.01
   X=0.0093
   GO TO 4
7  CONTINUE
   I=I+1
   L=100.
   PM=1.
   X=0.9896
   GO TO 4
8  CONTINUE
   I=I+1
   L=1.

```

```
      X=0.4926  
      GO TO 4  
9     CONTINUE  
      I=I+1  
      L=0.01  
      X=0.0098  
      GO TO 4  
10    CONTINUE  
      STOP  
      END
```

To see what happens in the down link, i.e. the ground to aircraft link, this program calculates the ERP of the satellite, the power received by the aircraft, the power transmitted by the ground, etc. The results show an improvement on this link compared to the up link. This is because of the assumption that ground power transmitted is high enough to overcome satellite receiver noise. The case investigated here is $a = 0$, $b = 1$.

```

C OTHER PERFORMANCE PARAMETERS FOR MASTERS THESIS
C PT=SUM OF ALL PI
C PI=POWER RECEIVED BY SATELLITE FROM ITH TRANSMITTER
C NW=SATELLITE RECEIVER NOISE POWER DENSITY
C NO=GROUND RECEIVER NOISE POWER DENSITY
C PRG=SATELLITE REPEATER POWER RECEIVED BY GROUND STATION
C BW=TOTAL RF BANDWIDTH
C JW=POWER IN SATELLITE DUE TO INTERFERENCE
C JO=POWER IN GROUND RECEIVER DUE TO INTERFERENCE
C ERPSG=EFFECTIVE RADIATED POWER FROM SATELLITE TO GROUND
C PTA=POWER TRANSMITTED FROM AIRCRAFT
C R=DISTANCE FROM SATELLITE TO GROUND STATION
C F=TRANSMITTING FREQUENCY IN MEGACYCLES
C PE=PROBABILITY OF ERROR (NOT NEEDED FOR THESE CALCULATIONS)
C LO=ATMOSPHERIC LOSSES (PATH LOSSES) AT UHF FREQUENCY
C P=PR/PT, A=JW/PT, B=JO/PR, RO=B*NW/PT, N=NW/NO, PM=PI/PT
  REAL N,PM,NW,NO,A,B,PRA1,PRA,ERPSA,GT,GR,BW,
    1 RO,X,K,PE,SNR,LO
  INTEGER I
  H=2400.
  GT=0.
  GR=0.
  F=400.
  R=22300.
  PE=10.**(-3)
  SNR=4.82
  NO=1.124*10.**(-20)
  LO=37.+20.*ALOG10(F)+20.*ALOG10(R)
  WRITE(6,40) LU
40 FORMAT(10X,F8.4)
C SHF=UHF LINK (DOWN LINK)
  WRITE(6,2)
2 FORMAT(1X,38H SHF=UHF LINK      RO      PRA1 IN WATTS,
145H      PRA IN DBW      BW IN HZ      ERPSA IN DBW,
27H      PM)
  N=1.
  PM=0.2
  NW=N*NO
  A=0.
  B=1.
  GO TO 4

```



```

5  PRA1=((K*SNR*NW*H)/X)
   PRA=10.*ALOG10(PRA1)
   ERPSA=PRA+LO-GT-GR
   BW=((RO*PRA1)/(NW))
   WRITE(6,3) RO,PRA1,PRA,BW,ERPSA,PM
3  FORMAT(15X,F8.4,6X,1PE8.2,8X,1PE8.2,6X,1PE8.2,7X,
10PF8.4,5X,F5.2)
   IF (I .EQ. 1) GO TO 10
   IF (I .EQ. 2) GO TO 11
   IF (I .EQ. 3) GO TO 12
   IF (I .EQ. 4) GO TO 13
4  CONTINUE
   I=1
   X=0.86
   K=1./PM
   RO =6.1
   GO TO 5
10 CONTINUE
   I=I+1
   X=0.82
   PM=1.
   K=1./PM
   RO=4.5
   GO TO 5
11 CONTINUE
   WRITE (6,14)
14  FORMAT(1X,13H UHF-UHF LINK)
   I=I+1
   X=0.0790
   PM=0.2
   K=1.
   RO=2.1
   GO TO 5
12 CONTINUE
   I=I+1
   X=0.3892
   PM=1.
   RO=1.7
   GO TO 5
13 CONTINUE
   STOP
   END

```

2. Time Division Multiplexing--can it be used? The following are calculations carried out to decide:

Data: Information Rate, $H = 2400$ data bits/sec

Transmitting frequency, $f_c = 4(10^8)$ cps

PN code period, $L = 31$

The PN bit period, $T_r = 1/H = \frac{1}{2400} = 0.00042$ sec/data bit

The PSK period, $T_{psk} = T_r/L = 0.00042/31 = 0.0000136$ sec/bit

One cycle period, $T_{f_c} = 1/f_c = 2.5(10^{-9})$ secs/cycle

The number of cycles per PSK bit, $f_{psk} = \frac{1.36(10^{-5})}{2.50(10^{-9})}$
 $= 5.44(10^3)$ cycles/bit.

This would be enough to determine the phase in that bit, thus TDM can be used.

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